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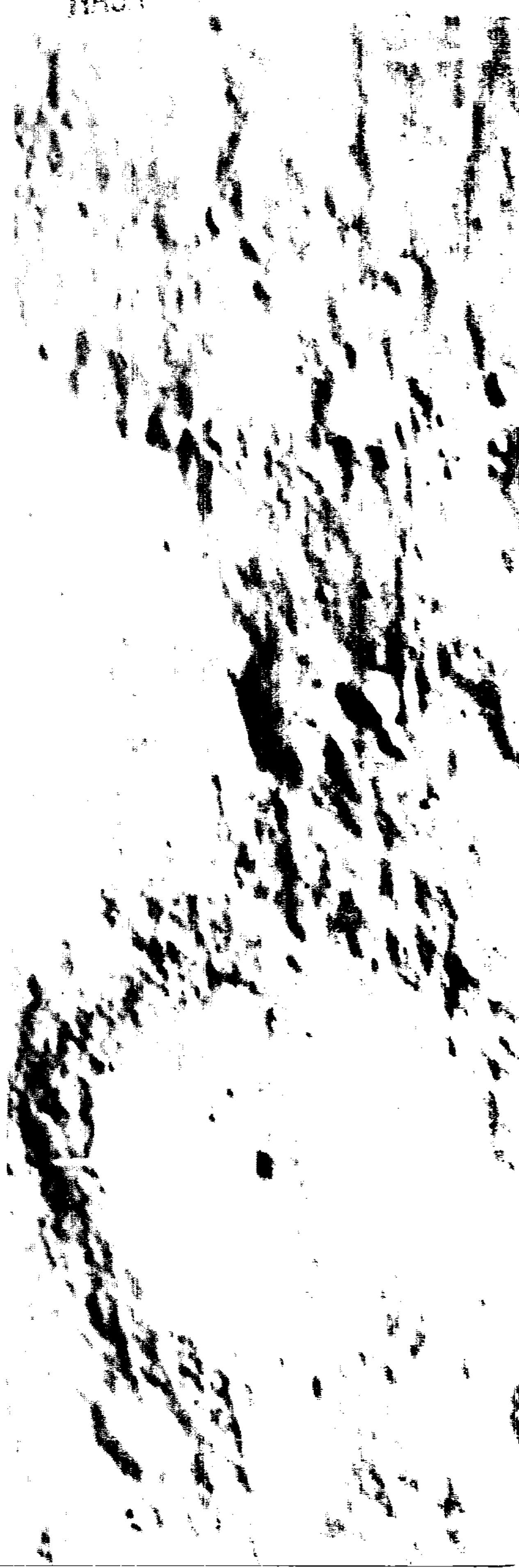
LUNAR SURFACE MOBILITY SYSTEMS COMPARISON AND EVOLUTION (MOBEV)

FINAL REPORT

VOLUME II

BOOK 2

MISSION ANALYSIS



BSR 1428

NOVEMBER 1966

The Bendix Corporation Aerospace Systems Division

FINAL REPORT

VOLUME I

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LUNAR SURFACE MOBILITY SYSTEMS COMPARISON AND EVOLUTION (MOBEV)

FINAL REPORT

VOLUME II
BOOK 2
MISSION ANALYSIS

BSR 1428

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER,
HUNTSVILLE, ALABAMA
UNDER CONTRACT NO. NAS8 - 20334

Approved by: C. J. Weatherred
C. J. Weatherred, Director
Lunar Vehicle Programs

NOVEMBER 1966

THE Bendix CORPORATION Aerospace Systems Division

FOREWORD

This document presents the results of the Lunar Surface Mobility Systems Comparison and Evolution Study (MOBEV) conducted for the National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama, under Contract NAS8-20334. The Bendix team responsible for the MOBEV Study includes Bendix Systems Division of The Bendix Corporation, Bell Aerosystems Company, and Lockheed Missiles and Space Company. Bendix, in addition to overall program management and system integration, has been responsible for LRV Systems, Mission Studies, and the MOBEV Methodology. Bell has been responsible for the Flying Vehicle Systems; Lockheed has been responsible for the LRV Human Factors, Environmental Control, Life Support, and Cabin Structures.

The study was performed by personnel of the Lunar Vehicle Program Directorate of Bendix Systems Division, The Bendix Corporation, under the direction of Mr. C. J. Weatherred, Program Director; Mr. R. E. Wong, Engineering Manager; and Mr. C. J. Muscolino, Project Manager, MOBEV. The NASA Technical Supervisor for the contract was Mr. Richard Love, R-P&VE-AA, Marshall Space Flight Center.

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SECTION 2

MISSION REQUIREMENTS SPECTRUM FOR EXPLORATION ROVING VEHICLES

Surface roving vehicles will be widely used in the collection of scientific data on the lunar surface because of their greater flexibility and economy of operation. A variety of tasks must be performed for which a number of different vehicles will be required. It is advantageous to meet the needs of the exploration program with the minimum number of vehicles to reduce the cost of vehicle development. This objective can be met in part by designing versatility into the vehicle, a characteristic which will be of advantage not only for reasons of economy, but also for operational flexibility.

The criterion of proper vehicle selection is the suitability of the vehicle to the fulfillment of mission objectives. The approach to the construction of a vehicle spectrum is to determine first a range of missions in terms of the variations in mission objectives. The associated vehicle spectrum is derived as a selection of design points which will provide at least one appropriate vehicle for each mission in the mission spectrum.

In this section a mission spectrum for exploration roving vehicles is presented with a rationale for its development.

2.1 SUMMARY OF REQUIREMENTS AND IDENTIFICATION OF MOBILITY GAPS

An initial exploration mission requirements spectrum for lunar roving vehicles was developed early in the program and is shown in Table 2-1. Each specification consists of four parameters: crew size, mission duration, range, and scientific payload; all bearing on mobility aspects of the mission.

In Section 2.5 the nominal mission for each point in the spectrum is presented. The bounds for manned missions are R1AE* and R4AE shown in Table 2-1. Mission requirements R0AE, an unmanned mission, are based on considerations of site certification requirements for manned missions.

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* For nomenclature see Table 2-1.

TABLE 2-1

INITIAL MOBILITY MISSION REQUIREMENTS SPECTRUM FOR EXPLORATION BY ROVING VEHICLE

		A	B	C	D
0	Unmanned				
	Duration	14 days	6 hr	90 days	90 days
	Range	6 km	3 km	200 km	800 km
	Payload	8 kg	75 kg	50 kg	50 kg (min)
1	One-Man				
	Duration	3 hr*	6 hr*	12 hr*	
	Range	8 km	30 km	40 km	
	Payload	10 kg	320 kg	320 kg	
2	Two-Man				
	Duration	6 hr*	8 days	14 days	28 days
	Range	30 km	250 km	400 km	800 km
	Payload	150 kg	320 kg	320 kg	320 kg
3	Three-Man				
	Duration	28 days	42 days		
	Range	800 km	1600 km		
	Payload	700 kg	1500 kg		
4	Four-Man				
	Duration	56 days			
	Range	2000 km			
	Payload	1500 kg			

Nomenclature Code: (Letter-Number-Letter-Letter)

1 First Letter: R for Roving Vehicle
2 Number: Normal Crew Size
3 Second Letter: Relative Mission Capability for Vehicles of a Particular Crew Size
4 Last Letter: E for Exploration Function

* Multiple sortie capability for 14 days, dependent on shelter or base for thermal control during launch and storage as well as recharge energy following each sortie.

After reviewing the system concepts resulting from this spectrum*, and the system and subsystem analyses conducted in the program, as well as additional recommendations from NASA, the initial spectrum was revised as shown in Table 2-2.

The mission requirements shown in Tables 2-1 and 2-2 cover the spectrum from the minimal to the maximal mobility mission. Requirements for intermediate missions can be met within the limits of the vehicles meeting the requirements shown. Existing vehicle concepts or designs will fulfill a portion of the spectrum. These are listed in Table 2-3. The remaining sets of requirements represent gaps in the present state of vehicle design. Conceptual designs for all requirements are provided in other volumes of this report and in the accompanying MOBEV Data Books.

2.2 MISSION OBJECTIVES

The evolutionary character of the lunar exploration program will lead to a continuing evolution in mission objectives. The sources of the evolution are the changing basis of scientific knowledge of the moon on which experiments are based, the increased performance and reliability of spacecraft delivery systems, and technological advances in support equipment.

The establishment of a mission spectrum is based on two primary sources, the recommendations of the scientific community and the Scientific Mission Support Studies which have been completed for various exploration system concpets.

The most complete and up-to-date sources of the scientific community appraisal are reports of two conferences held in the Summer of 1965, one by the National Academy of Sciences at Woods Hole, Mass. , and another

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* See reference 19, Section 5.

TABLE 2-2

FINAL EXPLORATION ROVING VEHICLE MISSION SPECTRUM

	A	A(1)	B	B(1)	C	D
0 Unmanned						
Duration	90 days		6 hr		90 days	
Range	72 km		15 km		200 km	
Payload	4 kg		75 kg		50 kg	
1 One-Man						
Duration	3 hr*	3 hr*	6 hr*	6 hr**		48 hr**
Range	12 km	12 km	30 km	30 km		125 km
Payload	10 kg	75 kg	320 kg	320 kg		320 kg
2 Two-Man						
Duration					14 days	
Range					400 km	
Payload					320 kg	
3 Three-Man						
Duration	28 days		42 days		14 days	90 days
Range	800 km		1600 km		400 km	3525 km
Payload	700 kg		1500 kg		320 kg	1500 kg

* Multiple sortie capability, dependent on shelter or base.

** Multiple sortie capability for 90 days duration, independent of shelter or base for thermal protection and recharge energy.

TABLE 2-3

EXISTING VEHICLE CONCEPTS CORRESPONDING
TO MOBILITY MISSION SPECIFICATIONS

Mission Requirements From Table 2-1	Applicable Existing Design, Concept or Derivation*
R0AE	SLRV
R0DE	LSSM Vehicles for Unmanned Operation
R1BE	LSSM, One-Man
R2AE	LSSM, Two-Man
R2BE	LESA requirement; MOLAB; MOLEM; MOCAN; MOCOM
R2CE	MOLAB; MOLEM; MOCAN; MOCOM

* For description and specific performance capabilities of these vehicles see Volume II, Book 1 and Volume II, Book 3, Appendix A.

by the Manned Space Coordinating Committee under the sponsorship of NASA at Falmouth, Mass. These reports cover an evaluation of present exploration concepts and recommendations for a program of lunar investigations, orbital and surface, and the use of the moon as a base for scientific experimentation. The program covers a 10-year period beginning with the first Apollo flights.

A series of Scientific Mission Support Studies were conducted to develop a description of scientific operations that can be carried out on the lunar surface within the capabilities of the exploration system concepts and to define the supporting requirements for such operations. The results of these studies include:

1. Definition of baseline scientific missions which consist of site selection recommendations and scientific experiments to be performed

2. Development of scientific instrument and mission operational plans including: (a) instrumentation mass, volume and shape factors, (b) power requirements and duty cycles, (c) data output and communications requirements, (d) environmental constraints, (e) instrument specifications for design and development, (f) description of operation of instruments, (g) sequencing of operations, and (h) lunar surface traverse description

3. Description of possible alternate missions

4. Recommendations for additional system capabilities to support the scientific missions.

These studies have been carried out for the Lunar Exploration Systems for Apollo (LESA) and Apollo Logistics Support System and are presently being conducted for Apollo Extension Systems (AES)* lunar surface missions. A further study, Scientific Mission Support for Extended Lunar Surface Missions, is presently being conducted to combine and correlate the results of these studies and other inputs to establish scientific inputs for long-range exploration program planning.

2. 2. 1 Scientific Community Appraisal

The broad goals of lunar exploration have been stated as follows: (1) obtain information from the moon to determine its environment composition, and gross body properties, (2) utilize the unique characteristics of the moon to establish observatories and laboratories for long-term scientific investigations, and (3) determine if lunar resources should be used for extended lunar operations, future interplanetary exploration, and terrestrial purposes.

The National Academy of Sciences, Space Science Board, meeting at Woods Hole, Mass. , in the Summer of 1965 undertook a study of certain principal areas of space research including lunar exploration. At the meeting major questions in the exploration of the moon were established. These questions pertain to the structure and process of the lunar interior, the composition and structure of the surface of the moon and the processes modifying the surface, and the history or evolutionary sequence of events by which the moon has arrived at its present configuration. Fifteen specific questions were formulated and are shown in Table 2-4.

Definition of the initial problems and projection of these problems to specific investigations and experiments is but the first step in the overall lunar scientific exploration development. A rationale or plan must be developed for obtaining the measurements. This requires consideration of the factors involved in temporal and spatial relationships. The technique of geologic mapping, supplemented by geophysical exploration and local drilling, is the primary means of solving the stratigraphic and structural relationships on the moon which are ultimately related to most of the objectives of lunar exploration.

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* This program is now known as the Apollo Applications Program (AAP).

TABLE 2-4

MAJOR QUESTIONS IN LUNAR EXPLORATION	
1.	What is the internal structure of the moon?
2.	What is the geometric shape of the moon?
3.	What is the present internal energy regime of the moon?
4.	What is the composition of the lunar surface?
5.	What principal processes are responsible for the present relief of the lunar surface?
6.	What is the present tectonic pattern and distribution of tectonic processes on the moon?
7.	What are the dominant processes of erosion, transport and deposition of material on the lunar surface?
8.	What volatile substances are present on or near the lunar surface?
9.	Are there organic and/or proto-organic molecules on the moon?
10.	What is the age of the moon and the age range of stratigraphic units on the lunar surface?
11.	What is the history of dynamic interaction between the earth and the moon?
12.	What is the thermal, the tectonic, and possible volcanic history of the moon?
13.	What has been the flux of solid objects striking the moon and how has that flux varied with time?
14.	What is the history of cosmic and solar radiation flux acting on the moon?
15.	What magnetic fields are retained in rocks on the lunar surface?

As stated by the Academy, "Investigations on the lunar surface are needed on at least three different scales. The smallest features, ranging in size from near microscopic to hundreds of meters, the fine structure of the lunar surface, can be studied by men on foot during early Apollo landings. Very detailed investigations of features at this scale and the processes by which they are produced may require a small lunar base to sustain men over much longer periods of time than are available during the early Apollo landings. To study features ranging in size from one to many km requires a vehicle to carry men over these distances from the landed spacecraft. This is the scale on which most of the contact relations of regional geologic units and mesoscale structures, such as relatively large craters, faults, folds, and possible igneous intrusions and volcanoes must be examined. Finally, surface traverses of ten to hundreds of km in length are required to examine features of crustal and subplanetary dimensions, such as the basin and surrounding mountain ring of Mare Imbrium and other circular-maria. These traverses are needed to obtain deep seismic reflection and refraction profiles correlated with surface gravity measurements and geology. Such traverses provide extensive opportunities to sample and study areal variations in the regional geologic units."

Following the National Academy of Sciences meeting, NASA conducted a Lunar Exploration and Science Conference to consider specific approaches to be taken in the exploration program. Working groups were established in the scientific disciplinary areas and specific recommendations developed. The following is a summary of the recommendations concerning mobility systems for use in exploration of the lunar surface.

"AES Manned Lunar Surface (AES-MLS)

"The AES-MLS is essentially a continuation of the early Apollo missions characterized by longer stay time and larger scientific payloads.

"It is suggested that this program can be usefully exploited in five or six missions, extending through 1974. The scientific requirements of this series include stay times up to 14 days and traverses up to 15 km from point of landing.

"The longer stay time will probably permit the collection of more material than can be returned to Earth. Hence aids to the selection of samples in the field or prior to return should be provided by analytical equipment which will also measure sample characteristics which may be altered by return or packaging. Sample return is still the most significant achievement in these missions. Local mapping should also have a high priority so that sample location is accurately tied to the local geology.

"The capability to off load several LSEPs during each AES mission is also an important aspect. In this way a small array of stations (LSEPs) could be set into operation, giving important information for revealing the internal properties of the moon.

"The moon should provide a unique base for astronomers because of its useful environmental characteristics, the most important being the lack of an appreciable atmosphere. However, exhaustive studies of the complete lunar environment are necessary before engineering design can be started.

"The primary objective of analytical devices used on the lunar surface should be to extend the power of the observer to differentiate materials which have similar characteristics. The optimum sample return capability would be between 200 and 250 kg (450-600 lb) per mission. The following basic types of equipment are required for this phase of lunar exploration.

1. Automatic position recording systems. Essential for tracking and recording movements of the astronaut, and the roving vehicle, and knowing the orientation of the camera. The system would automatically telemeter this information back to Earth or to the LM.

2. Local Scientific Survey Module (LSSM). This surface roving vehicle should have the capability of carrying either one or two suited astronauts and a scientific payload of at least 600 lb. Operational range of 8 km radius is a minimum, and 15 km would be more useful. Remote control of the LSSM would also be advantageous both before and after the arrival of the astronauts.

3. Lunar Flying Vehicle (LFV). A LFV would be useful for extending the operational range of the AES and for studying features inaccessible to the LSSM due to topography. It should be able to carry at least a 300 lb scientific payload over a distance of 15 km. Continued study should determine how effectively it can be employed in surface operation.

4. Lunar Drills. The development of a 1 in. drill capable of penetrating to a depth of 3 m in either rubble or solid rock is recommended. It should be operable from a roving vehicle. It is necessary for lunar heat flow studies and for obtaining biological samples.

"Because of the liberal weight allowance for equipment delivered to the moon's surface most Working Groups indicated a wide variety of experiments desired for inclusion in the program. Equipment and experiments include instrumentation for performing gravity surveys, active seismic surveys, magnetic measurements, radioactivity measurements, environmental measurements, and in general instrumentation and supporting equipment for conducting geological-geophysical surveys on the lunar surface.

"To obtain maximum output of scientific information from these experiments, astronauts should be given scientific training in specific rather than general areas. The greatest need is for trained geologists; however, specialized training will be required in physics, meteorology, chemistry and other fields.

"Post-AES

"The AES should be followed by a program including long distance travel, up to 800 km and fixed site investigation from two months to one year. These missions should commence about 1975 and proceed at a rate of one per year through 1980. Additional orbital flights also appear desirable during this period so as to conduct simultaneous orbital and surface missions.

"A long-range laboratory vehicle for geological and geophysical exploration is required to permit the collection of data to form a broad regional integrated picture of the surface geology and crustal structure. These data will also be essential as a basis for interpretation of the imagery and measurements obtained from the remote sensing orbital vehicle and also to substantiate other investigations.

"A series of traverses along the equatorial belt is suggested, requiring a vehicle with the following characteristics:

1. "A minimum range of 800 km

2. Shelter for a three-man crew

3. Mission duration capability of up to two months

4. Not be constrained to return to starting point

"A Lunar Base is a surface complex which will allow longer stay time, possibly up to a year, than is presently envisioned by the AES concept. Primary needs for a base are visualized to be:

1. "The measurement of presently occurring time varying phenomena - many are geophysical in nature

2. The study of lunar surface processes

3. Deep drilling studies are most important for information on early history, crustal composition, and surface properties of the past. Depth to be reached should probably exceed 300 m

4. Detailed study of a critical field area

5. Construction and manning of large radio and optical telescopes, yet to be defined."

2.2.2 Scientific Mission Support Studies

2.2.2.1 Apollo Extension Systems (AES)

The purpose of the study was to derive scientific mission plans for alternate AES payloads; namely, the LM-Shelter and a single Local Scientific Survey Module (LSSM), a Manned Flying System (MFS), two LSSMs, or a combination LSSM and MFS. Table 2-5 summarizes the results of the study for the several lunar roving vehicle baseline scientific missions. Table 2-6 shows a typical vehicle payload for geological and geophysical reconnaissance sorties. The following paragraphs summarize the lunar roving vehicle mission portions of the study.

TABLE 2-5

BASELINE SCIENTIFIC MISSIONS - AES

			2 LSSM		
		LSSM	Manned	Unmanned	LSSM/MFS
1.	Range	192 km	136	97	146 km
2.	Radius of Operation	8 km	8 km	8 km	8 km
3.	Number of Sorties	12	12	2	9
4.	Time Utilization				
	On Stations	27.5 hr	41.75 hr	16 hr	21.75 hr
	Driving	38.5 hr	27.25 hr	32 hr	29.25 hr
5.	Maximum Scientific Payload				
	Weight	326 kg	238 kg	14 kg	238 kg
	Volume	1 m^3	0.75 m^3	0.02 m^3	0.75 m^3
6.	Scientific Power				
	Average Power	150 w	165 w	50 w	130 w
	Peak Power	700 w	700 w	75 w	700 w
	Total Energy	10 kw/hr	11.2 kw/hr	800 w/hr	6.8 kw/hr
7.	Communications				
	On Stations	Voice TV-500 kc 4 analog channels 1.6 kb/sec digital	same	TV 500 bps digital	same
	Driving	Voice 1 analog channel 1.6 kb/sec digital	same	TV	same

TABLE 2-6

AES - SCIENTIFIC PAYLOAD MAKEUP
LSSM - GEOLOGICAL/GEOPHYSICAL RECONNAISSANCE

Item	Weight (kg)	Power (w)
Theodolite/Ranging Laser	22.8	20
Surveying Markers - 20	4.0	-
Sketchboard and Maps	2.3	-
Ground Truth Package	44.0	-
TV	-	25
Film Cameras - 2	-	150
Full Package	-	450
Gravimeter	6.8	6
Magnetometer	3.9	6.3
Nuclear Package	15.6	-
Spectral and Natural Gamma	-	17
Gamma-Gamma	-	-
Neutron-Neutron	-	35
Neutron-Gamma	-	25
Sample Containers	1.0	-
Surveying Staff	13.2	-
Vehicle Mounted Support	7.0	10
Hand Tools	15.0	-
*In Situ		
Penetrometer	2.8	7
Surface Electrical	13.1	55
Radiometry	4.0	40
*Shallow Seismic Refraction		
Basic Equipment	71.0	42
Charges and Detonators	3.0	-
Gas Analysis	7.0	26
Astronaut Hazards	1.4	1.8
Data Handling and Signal Conditioning		
Displays	2	5
Multiplexers and Programmer	9	23
Cabling and Equipment Stowage	9	-
Total Weight/Sortie: 184 - 238 kg		

*One carried but not both

Missions Utilizing Single LSSM

During the basic mission, exploration will take place within 8 km of the LM-Shelter. Twelve scientific sorties are planned with a total traverse of 192 km. Maximum time per sortie is 6 hours. Total traverse time is 66 hours of which 38.4 hours will be spent driving and 27.6 at scientific stations. Scientific activities include geological and geophysical reconnaissance, geological observation, including 10-ft core hole drilling, and deep refraction seismic surveys. The LSSM will carry one astronaut in space suit (open cockpit) and a scientific payload of 320 kg.

An alternative mission with emphasis on expanded Emplaced Scientific Stations (ESS) capability was also considered. Three satellite ESS stations with a total weight of 197.7 kg are emplaced in a pattern about the central ESS station. Because of limitations on astronaut time and payload weight, the 100-ft drill is eliminated. However, more payload weight is allowed for the seismic experiments. Total scientific payload weight is 808.2 kg; total range is 219 km over a total of 13 sorties.

An extended mission was also considered in which the LSSM is utilized in an unmanned mode after the departure of the astronaut crew. A remote control capability and stereo television is required. Direct communication with the earth station will remove the restriction of operating near a base. Requirements for mobility performance and scientific experiment capability can be adapted to specific missions. The following are proposed as typical characteristics for the unmanned part of the mission: mission duration, 14 days or less; range in the unmanned mode, 150 km; experiments, high resolution TV views in addition to TV usage for remote driving of the LSSM, continuous magnetic and nuclear surveys, and possibly gas measurements. Payload weight can be greatly reduced for the unmanned exploration by unloading the equipment for other experiments.

Missions Utilizing Two LSSMs

In the mission considered, the two vehicles have distinct roles and differ considerably in capabilities. The mode of utilization is also different. One vehicle is equipped for manned exploration with manual control; the other, for remote control from an earth station. Efficiency in the use of the unmanned vehicle is increased by reports of visual observations of the astronaut crew. The unmanned vehicle is used to increase astronaut safety by reconnaissance prior to manned excursions and by serving in a standby mode for emergency use when manned sorties are conducted beyond a specified distance. After the departure of the astronaut crew, the unmanned LSSM will be used for further exploration by remote control. Since communication links between the LSSM and the earth station are direct, the radius of operation is unrestricted. The 100-ft drill and the ESS have been eliminated to meet weight restrictions. More effort is allocated to the astronomy experiments than in the single LSSM mission to replace the 100-ft core drilling.

Missions Utilizing One LSSM and One MFS

The use of two dissimilar vehicles, one with extended range and the other with high mobility, places the emphasis in this mission on mobility. Again, the use of vehicles is scheduled so as to increase astronaut safety by having the vehicle which is not in use on emergency standby. Neither the 100-ft drill nor the ESS are included in the scientific payload. Both LSSM and MFS sorties are confined to an 8 km radius in the mission considered. The MFS sorties differ from the LSSM sorties in that less time is spent in travel so that more is available on station. The MFS can also be used to reach sites not accessible to the LSSM, but in that case the LSSM has no value as emergency standby while the astronaut is on station.

2.2.2.2 Apollo Logistics Support System (ALSS)

The scientific mission studies for ALSS were concerned with the traverse requirements and associated instrumentation and experiments to be performed with a mobile laboratory vehicle.

The MOLAB mission calls for completing a traverse of 275 km in 14 days with a scientific payload weight of 318 kg. In addition to providing a shirtsleeve environment for the crew of two astronauts, the vehicle will also provide space and facilities for analysis of specimens, for data processing and communication with earth stations, and for supplying necessary power.

Table 2-7 summarizes the mission requirements as extracted from this study. Table 2-8 summarizes the characteristics of the recommended scientific instrument package.

TABLE 2-7

ALSS-MOLAB SCIENTIFIC MISSION SUMMARY

1.	Range	275 km
2.	Radius of Operation	80 km
3.	Crew Size	2
4.	Duration	14 days
5.	Time Utilization	
	On Stations	306 hr
	Driving	30 hr
	EVA	86.5 man hr
6.	Ingress/Egress Cycles	28
7.	Scientific Payload	
	Mass	318 kg
	Volume	1 m^3
8.	Scientific Power	
	Average Power	500 w
	Peak Power	3200 w
	Total Energy	75 kwh
9.	Communications	
	On Stations	Voice TV 51.2 kb/sec digital
	Driving	Voice TV 4.7 kb/sec

TABLE 2-8

ALSS-MOLAB RECOMMENDED SCIENTIFIC INSTRUMENT PACKAGE

Instrument	Mass (kg)	Volume (cm^3)	Power (w)
Core Drill	85.4	643,252	3252
Mining Core Splitter	2.5	1,969	0
Nuclear Experiments Package, which includes:			
Gamma source, gamma detector, count rate meter, data processor, 128 channel analyzer, source-detector shield	15.6	3,496	52
Active Seismic Package, which includes:			
Six geophones, 200 m cable, amp system, tapes, packaging and shock mount, explosives, detonators, 10 receivers	21.4	43,500	10
Sonic Velocity:			
Active seismic components plus wall coupling, cable, geophone, 15 squibs, acoustic velocity instrument	4.9	15,476	-----
70 mm Framing Cameras (4)	10.0	13,520	300
Radiometer	7.0	8,340	20
Spectroradiometer	10.0	70,300	50
Interferometer Spectrometer	4.0	3,790	10
TV	5.0	3,195	15
Platform and Mounting for Boresighted Pkg	3.0	N/A	-----
Film Readout Device	9.1	16,400	20
Falling Ball Gravimeter	2.7	2,125	3
LaCoste-Romberg Gravimeter (w/battery)	5.9	6,936	4
Quadrupole Mass Spectrometer	4.55	8,430	28
Metastable He Magnetometer	4.0	3,848	5
Core Hole Electrical Induction Logging Sonde	2.3	100	2
EM Probing Equipment			
Antennas, Impedance Measuring Device	2.7	14,200	2
Penetrometer	2.7	7,549	7
Surface Electrical Package, which includes:			
Resistivity meter, potentiometer, cables, and electronics	1.5	797	26
Apollo-Inherited Equipments	31.7	92,984	33.8
Radiation Hazard Instruments	2.8	2,140	1.8
Data Handling, Storage Display	30.0	41,840	98.0
Internal Cabling	4.4	18,000	-----
Experiment Connection Panel	2.4	8,200	-----
Equipment Storage	42.45	-----	-----
Total	318.00	1,030,387	3934.6

2.2.2.3 Lunar Exploration Systems for Apollo (LESA)

The results presented in this section are based on the scientific mission support study.

The four levels of activity shown in Table 2-9 have been developed for the system concepts. Each level provides for definite types of missions and mission objectives; however, the systems are modular in design so that those at lower levels can be extended to higher levels by delivering additional system components. Thus lunar basing can be accomplished on an evolutionary basis, and an expansion of the program can be implemented without material loss.

The utilization of the permanent base permits a greatly extended period of operation and a more complete scientific program. A variety of vehicles is needed, including exploration vehicles for both local and extended traverses. Although the amount of effort which can be expended on exploration is different for the different system concepts, the type of exploration is determined according to the exploration stage reached.

Table 2-10 shows the breakdown of astronaut scientific man-hours into traverse and base centered activities. Also shown is a breakdown into the time spent inside and outside the life support cabins of bases or vehicles. The totals shown for the four LESA models are based on mission requirements and not system design capabilities. Table 2-11 shows the allocation of scientific time on traverse to general reconnaissance, the investigation of specific features, and the investigation of features of significance encountered during the traverse.

Estimates of the total amount of data and of the average data rate are shown for the four LESA models in Table 2-12. Average power requirements and total energy requirements are shown in Table 2-13.

The full span of traverse objectives can be observed in the development of a base starting with the LESA 1 model and building up to LESA 4. During the LESA 1 traverses the emphasis will be on a general reconnaissance of the area within a 75-mile radius of the base rather than in completing specific individual experiments. Geologic maps will be prepared and important topographic features identified. Samples will be collected for analysis at the base to aid in planning the scientific program

TABLE 2-9

LUNAR BASE OCCUPANCY IN
MAN MONTHS FOR LESA BASES

LESA MODEL	BASELINE MISSION		
	Number of Men	Duration (Months)	Total Man Months
LESA 1	3	3	9
LESA 2	6	6	36
LESA 3	12	12	144
LESA 4	18	24	432

TABLE 2-10

ALLOCATION OF ASTRONAUT SCIENTIFIC TIME
TO INSIDE AND OUTSIDE ACTIVITIES
FOR LESA MISSIONS

Baseline Model	Location	Inside Activities (man hr)	Outside Activities (man hr)	Total
LESA 1	Base	1,085	51	1,136
	On Traverse	302	135	437
	Total	1,387	186	1,573
LESA 2	Base	6,211	375	6,586
	On Traverse	763	302	1,065
	Total	6,974	677	7,651
LESA 3	Base	17,292	1,142	18,434
	On Traverse	2,315	558	2,873
	Total	19,607	1,700	21,307
LESA 4	Base	45,924	2,124	48,048
	On Traverse	5,010	1,090	6,100
	Total	50,934	3,214	54,148

TABLE 2-11

ALLOCATION OF TRAVERSE TIME FOR LESA BASES

SCIENTIFIC OBJECTIVES	TIME ALLOCATION			
	LESA 1	LESA 2	LESA 3	LESA 4
General Reconnaissance	70%	60%	30%	10%
Investigation of Specific Features	15	20	40	80
Investigation of Features Adventitiously Encountered	15	20	30	10
TOTAL	100%	100%	100%	100%

TABLE 2-12

DATA TRANSMISSION REQUIREMENTS FOR LESA BASES

LESA Model	Total Scientific Data (bits)	Operational Period (hr)	Average Data Rate (bits/hr)
LESA 1	6.0×10^{9}	2,000	3.0×10^{6}
LESA 2	1.3×10^{10}	4,000	3.2×10^{6}
LESA 3	1.3×10^{10}	8,000	1.6×10^{6}
LESA 4	2.3×10^{10}	16,000	1.4×10^{6}

TABLE 2-13

COMPARISON OF POWER REQUIREMENTS* FOR SCIENTIFIC ACTIVITIES FOR LESA BASES

Model	Power (kw) Base	Power (kw) Traverse**	Total Energy (kwh) Base	Total Energy (kwh) Traverse**
LESA 1	0.40	0.18	200	3.6
LESA 2	0.85	0.20	560	20
LESA 3	4.0	0.25	12,000	210
LESA 4	37.0	0.20	83,000	290

*Excluding power for drilling

**Per vehicle

for the LESA 2 through LESA 4 bases. Automatic instrument stations will be emplaced. Limited seismic surveys will be made using the roving vehicle and the base as a two station system. Geophysical surveys will be made to determine the ranges in which observations can be expected to fall in more complete studies. The capabilities and limitations of the vehicle will be determined with a view to selecting suitable routes for later operations. Finally, scientific instruments will be tested in use in the lunar environment and improvements suggested in their design and operation.

In later phases, the scientific investigations become more complex and time consuming, and the traverse range is increased. In LESA 2, if the major use of the roving vehicle is to extend the geosciences reconnaissances started in LESA 1, the routes established during LESA 1 will be utilized in reaching outlying areas. This approach will permit the collection of comparative data and the servicing of Emplaced Scientific Stations. During LESA 3 and 4, detailed geologic, geophysical and geochemical studies will be conducted. Activities will include deep core drilling, long range seismic experiments, detailed study and mapping of selected features, and, if needed, high accuracy surveying.

As part of the Scientific Mission Support Study, several recommendations were made on the design anduse of roving vehicles. Substantial increases in stay-time are needed for extended traverses, as indicated:

Model	Minimum Stay-Time
LESA 1	11 days
LESA 2	14 days
LESA 3	16 days
LESA 4	18 days

An increase in space suit time from two to four hours was also recommended. To improve the sampling rate, instruments should be designed for use from within the vehicle wherever possible. Instruments which can be operated while the vehicle is in motion can provide a continuous record if required. The penetration of the vehicle wheels into the lunar surface should be monitored to provide data for an analysis of soil mechanics. Other instruments can be used during brief stops on route. Another possibility for making scientific measurements between stations should also be explored. The proposed method is to drag an instrument cable behind the vehicle to obtain certain geophysical data. In any event, the collection of scientific data between major scientific stations should be provided for. A means of positioning the vehicle over a benchmark and a capability for performing triangulation surveying from inside the vehicle should also be provided.

2.3 EXPLORATION SYSTEM CONCEPTS

A number of exploration system concepts have been investigated or are under development for lunar exploration. The most noteworthy of these have been Surveyor (Unmanned), Apollo, Apollo Applications Program (AAP, formerly known as AES), Apollo Logistics Support System (ALSS), and Lunar Exploration Systems for Apollo (LESA).

2.3.1 Surveyor

Surveyor payloads and missions are designed to achieve engineering objectives. Primary considerations are those of achieving a successful soft landing and spacecraft operation, and certifying a site for the first Apollo landing.

The launch vehicle will be an Atlas-Centaur and the total payload mass is 1112 kg of which 51.8 kg is scientific payload.

As originally planned, if the first four flights obtain the necessary data for Apollo site certification, the remaining four flights can conduct additional scientific experiments; namely, a lunar seismology experiment, compositional determination by an alpha-scattering device, and a micrometeorite experiment.

Early advanced Surveyors considered the possibility of the addition of a small roving vehicle to be delivered with the basic spacecraft. The SLRV, Surveyor Lunar Roving Vehicle, concept is a small unmanned roving vehicle, having a mass of 45.5 kg. The LRV examines a potential Apollo landing site to verify its suitability. One proposed technique is to explore an area, approximately 3200 m in diameter, with 19 separate survey points whose diameters are 40 m.

In addition to the basic design concept, the possibility exists for delivering the Surveyor spacecraft from lunar orbiting vehicles allowing an increase in scientific payload to about 175 kg.

2.3.2 Apollo

The Apollo system for surface operations is the Lunar Module (LM). It is designed to carry two men and the required support equipment from lunar orbit to the lunar surface, to provide support for the astronauts while on the surface, and to return the men and lunar samples to the earth return vehicle (Command Service Module) in lunar orbit. The vehicle provides a pressurized oxygen environment, food, water, communications equipment and environmental control for the crew for a period up to 45 hours. Surface stay-time is variable and may extend up to 35 hours. Spacesuits and portable life support systems are provided to permit four extra-vehicular activity excursions lasting three hours each for a total of 12 man-hours on the lunar surface. The excursions are limited to a 1000-ft radius of the LM. Principal activities include deployment of the Apollo Lunar Surface Experiments Package (ALSEP) and sample gathering for Earth return. One hundred and fourteen kilograms of scientific equipment may be carried to the surface and 36 kilograms of samples, data tapes, and photographic film may be returned to Earth.

2.3.3 Apollo Applications Program (AAP)

The Apollo Applications Program (formerly known as the Apollo Extension Systems) has been proposed as a means of extending the capabilities of the Apollo systems. The lunar surface system of AAP consists of a LM-Shelter (a modified LM) and support equipment, and a LM-Taxi for delivery of two scientist-astronauts. The support equipment may consist of scientific equipment, a roving vehicle known as the Lunar Scientific Survey Module (LSSM), and a lunar Manned Flying System (MFS). Other AAP system concepts include provisions for Earth orbital and lunar orbital laboratories. The LM-Shelter will provide two astronauts with living quarters and laboratory facilities for a stay-time on the lunar surface of up to 14 days. Mobility for excursions away from the LM-Shelter will be provided by the LSSM and the MFS.

The payload that can be carried on the LM-Shelter is a function of the mission duration as shown in Figure 2-1. The lower curve shows the payload if 14-day propellant tanks are used and off-loaded for the shorter missions. The upper curve is the payload if the tanks are made only large enough for the required duration.

No payload is to be delivered aboard the LM-Taxi, but 114 kg of samples, data tapes, and film may be returned.

2.3.4 Apollo Logistics Support System (ALSS)

An earlier concept for extending the Apollo systems capability is the ALSS. This concept also involves two flights to the lunar surface, one for delivery of equipment and the other for the crew delivery. The equipment delivery device is a modified LM descent stage (LM-Truck) capable of landing unmanned up to 4681 kg of payload; however, a contingency factor is used which reduces the payload mass to 3864 kg.

ALSS payloads may consist of a Mobile Laboratory (MOLAB) system capable of traversing the lunar surface for ranges up to 400 km and providing an environmentally controlled cabin or laboratory to support two scientist-astronauts for surface stay-times of 14 days, or a combination of a fixed lunar shelter laboratory and small surface vehicle or manned flying system. All payloads must be packaged within the LM-Truck envelope.

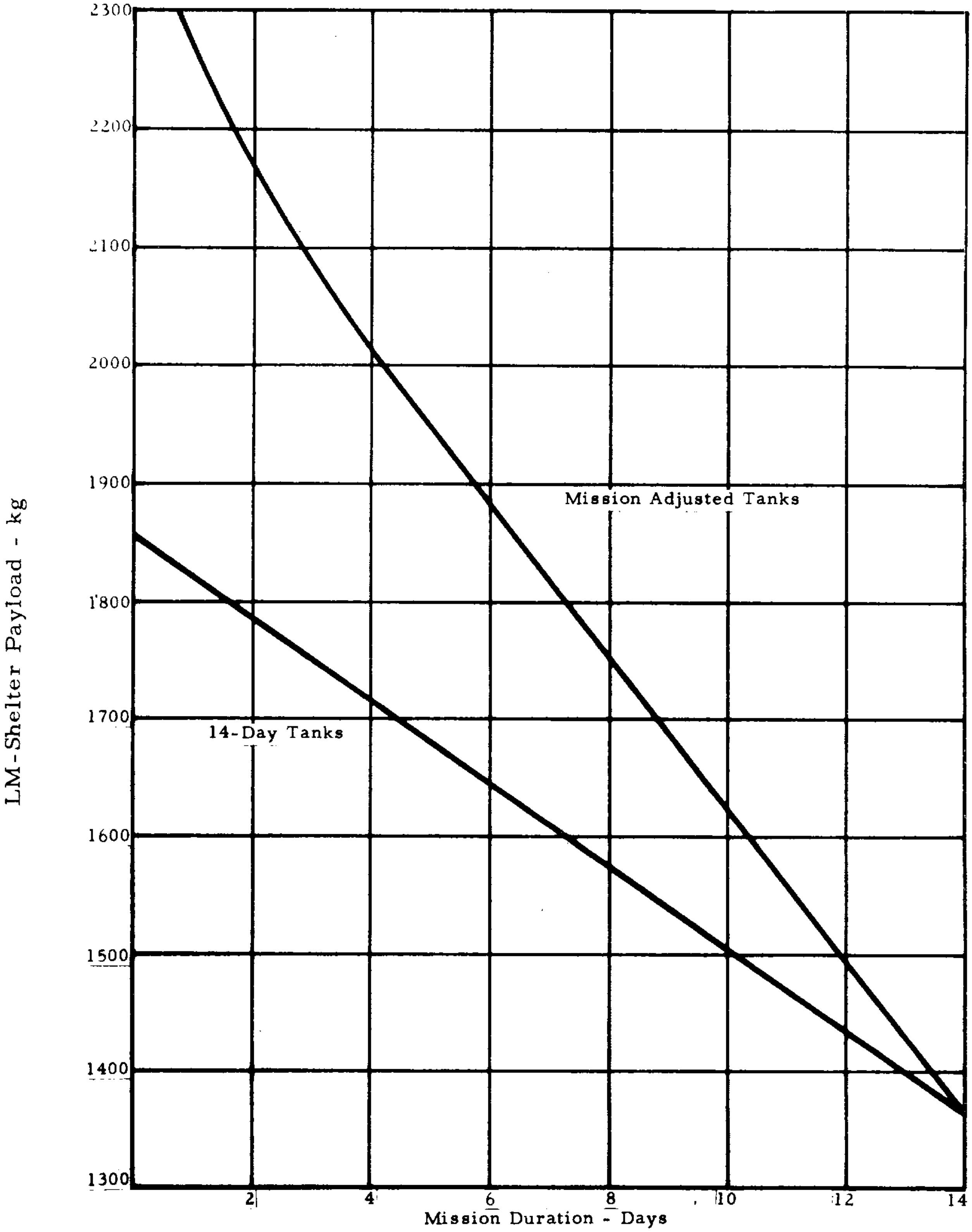

Figure 2-1 LM-Shelter Payload vs. Mission Duration

The MOLAB system is designed to provide extensive areal coverage about an 80 km radius around the landing site. The scientific payload capability is 318 kg consisting of instruments for obtaining geophysical profiles, subsurface core samples and extensive geochemical surveys. A flying vehicle may also be incorporated in the MOLAB concept to provide an emergency rescue means or for augmenting the exploration capability by extensions into areas inaccessible by surface locomotion means.

Lunar shelter laboratory concepts studied range from short duration emergency shelters to extended stay shelters ranging in months of duration, see Table 2-14. Small surface vehicles may include those with open cabins and durations of six hours up to small vehicles with cabins capable of up to 48 hours operating duration.

2.3.5 Lunar Exploration Systems for Apollo (LESA)

The Lunar Exploration Systems for Apollo (LESA) are lunar base concepts. The system consists of a family of prefabricated modules that can be assembled on or below the lunar surface in a variety of arrays to support a range of missions. The modules and equipment are to be transported to the lunar surface by a Saturn V Lunar Logistics Vehicle (LLV) which has a payload capability of about 25,000 lb. Delivery and return of the crew are accomplished by separate Saturn V launches. A number of base models have been established with crew sizes varying from 3 to 18 men and base durations of from three months to over two years, see Table 2-15. In addition to the basic shelters, the LESA concept has the capability for supporting a variety of exploration equipments including MOLAB, smaller surface reconnaissance vehicles, and large scientific equipment installations such as a 120-in. telescope or deep drilling mechanisms.

TABLE 2-14

LM-TRUCK SHELTERS

	Mass (kg)	Crew Size	Stay Time	Available for Payload*** (kg)
1*	2, 846	2	50 days	1, 694
2*	3, 904	3	60 days	636
3*	---	3	90 days	---
4*	4, 540	3	180 days	0
5**	1, 880	2	14 days	2, 660

*MIMOSA Second Monthly Progress Report, February 1966. Lockheed Missiles & Space Company

**ALSS, MOLAB Studies, Separate Shelter/Rover Conceptual Design and Evaluations, NASA Contractor Report CR-61049

***Assuming a maximum gross mass capability of 4681 kg.

TABLE 2-15

LESA BASE MODEL SUMMARY

	Model 1	Model 2	Model 3	Model 4
Crew Size	3	6	12	18
Base Duration	3 months	6 months	12 months	24 months
Scientific Equipment	400 kg	1150 kg	1815 kg	6200 kg
No. of Vehicles	1	1	2	3
Vehicle Crew Size	2	2	2	2
Vehicle Duration	5 days	8 days	8 days	8 days
Vehicle Range	320 km	480 km	480 km	480 km
No. of Sorties	7	9	9	9
Vehicle Mass	2500 kg	2500 kg	2500 kg	2500 kg
No. of LLV Payloads	1	2	3	8

2.4 NOMINAL MISSION SPECTRUM

This section presents the complete spectrum of nominal missions for exploration roving vehicles. This spectrum includes the following missions: (1) those derived from past studies (e.g., SLRV and MOLAB), (2) considerations of what would logically constitute a maximum and minimum manned mission consistent with exploration objectives and exploration system concepts and (3) intermediate missions consistent with delivery system capabilities and exploration system concepts.

2.4.1 Unmanned Missions

2.4.1.1 Site Selection (R0AE)

A vehicle mission was originally conceived for the Apollo site selection program. This vehicle is to be carried to the lunar surface by a Surveyor and be capable of traveling freely across the surface. The mission consists of measurements of lateral variation of surface and subsurface parameters and for investigation of specific lunar structural and morphological problems which would require extreme landing accuracy for a stationary lander. The vehicle is to be operated in lunar day only, thus the mission duration is 14 days. In order to minimize the number of earth stations to be utilized, the vehicle is operated for 9 hours/day maximum. The total range required is 6 km which provides for a statistical sampling of an area 3200 m in diameter around the landing point with 19 separate survey points whose diameters are 40 m. The scientific equipment (8 kg) to be carried consists of stereo TV, an odometer and a solar aspect sensor. Power requirements are 30 w average and 35 w peak. A modification to the basic design would include addition of an RTG-battery power system which provides lunar night survival and operation for a 90-day time period with attendant increase in range to 40 km and scientific payload accommodation (4 kg and about 10 w).

2.4.1.2 Astronaut Assist (R0BE)

This mission is a short duration (3-5 days) manned exploration possibly using an extended Apollo type module. This operation will consist primarily of on-foot reconnaissance and possibly emplacement of several emplaced scientific stations for extended operation. A vehicle may be provided to assist the astronaut in transporting and deploying these packages. The payload capability should exceed the single package carrying capability of the astronaut (probably about 75 kg). The radius and range should be within the walking capability of the astronaut (3 km radius). There should be a total of about five sorties available. The duration of each sortie should be about six hours or the limit of a two backpack operation. No power or communications support are required for scientific equipment as it will all be self contained.

2.4.1.3 Extended Unmanned Exploration (ROCE)

The possibility of delivery of a Surveyor probe from a lunar orbiting vehicle allows an unmanned vehicle to be delivered virtually anywhere on the lunar surface. The unmanned rover has four roles in the lunar exploration program:

1. Reconnaissance across zones of discontinuities or rapidly-changing properties to obtain sufficient understanding so that a judgement can be made as to whether the zone is significant enough to commit a manned landing.

2. Linear traverses at polar and backside areas where manned vehicles are not likely to be sent.

3. Visual description and specific analyses of certain structural and morphological features which cannot be reached by man.

4. Lateral extension of surface coverage of one or more measurements from the landing point of a stationary probe.

The measurements to be conducted include the following:

1. Monoscopic, high resolution (0. 1 mm), color images of the near vicinity of the vehicle to provide a broad context on the five-scale surface geometry.

2. Active seismic studies to obtain data on the subsurface configuration.

3. X-ray fluorescence to obtain in situ analysis of the lethologic character of the surface material.

4. Continuous analysis of materials properties by gamma-ray spectroscopy and gamma backscatter, and surface hardness.

The vehicle should have a total range capability of 200 km and a duration of 90 days. Approximately 10 stops per day will be made for detailed analysis. Three hours per day will be spent on stations.

Table 2-17 summarizes the scientific equipment characteristics.

2.4.1.4 Remote Vehicle Operation as an Adjunct or Extension of Manned Missions (R0DE)

A mission has been postulated in which the vehicle is delivered to the lunar surface with the LM-Shelter or a LM-Truck Shelter and can be utilized before, during and after the manned mission to explore areas prior to committing a man and to extend the data obtained during the manned mission to a much larger area. The vehicle should have a total range capability of about 800 km which may be utilized in a detailed, intensive survey pattern or on a linear traverse across a boundary area. The vehicle should have a mission duration of 90 days with vehicle usage of about 6 hours/day, the capability of a single ground station. The number of stations will vary with the area covered but should average about 4 stops per day with the time on station averaging about 30 min. The scientific equipment to be utilized is summarized in Table 2-18. Data rates required are TV plus 368 bits/sec during drive and TV plus 14.9 kbits/sec on station.

2.4.2 Single Crew Missions

2.4.2.1 Apollo Mission Mobility Augmentation (R1AE, R1A(1)E)

As an alternate to the primary Apollo mission of landing a two man crew for on-foot exploration and deployment of an emplaced experiment complement, it is proposed that a small vehicle replace the experiment package (114 kg) which would allow reconnaissance and sample collection over a wider variety of terrain features. The vehicle would be essentially a minimal manned concept completely self-contained. Mission duration is three hours, the scheduled limit of the PLSS. Crew size is one man. Mission range should be consistent with the mission duration of three hours or about 12 km. The vehicle should be capable of carrying about 10 kg of hand tools and returning an additional 10 kg of geological specimens. No power or communications support are required.

TABLE 2-16

ROCE SCIENTIFIC EQUIPMENT LIST

Instrument	Mass (kg)	Volume (cm^3)	Power (w)	Duty Cycle
Television - Monoscopic, visible images of vicinity of vehicle, resolution 1:100	6.4	4920	150	25% drive
Television - high resolution (0.1 mm) images of area within a few meters	2.7	4920	150	40% on station
Active Seismic - Geophone and charges	9.1	820	1	30 min total
X-Ray Fluorescence	9.1	16400	25	20% on station
Gamma-Gamma Backscatter	4.5	3280	10	20% on station
Gamma-Ray Spectrometer	8.2	4100	3	100%
Penetrometer	2.7	7560	7	100%
TOTAL	42.7	42000		

TABLE 2-17

RODE SCIENTIFIC EQUIPMENT LIST

Instrument	Mass (kg)	Volume (cm^3)	Power (w)	Duty Cycle
Television - Monoscopic, visible images of vicinity of vehicle, resolution 1:100	6.4	4920	150	100% drive
Television - High resolution (0.1 mm) images of area within a few m	2.7	4920	150	100% on station
Active Seismic	9.1	820	1	30 min total
X-Ray Fluorescence	9.1	16400	25	10% on station
Gamma-Gamma Backscatter	4.5	3280	10	10% on station
Gamma-Ray Spectrometer	8.2	4100	3	100%
Penetrometer	2.7	7560	7	100%
Quadrupole Mass Spectrometer	7.5	4690	23	100%
Petrographic Microscope	9.0	5400	30	2% on station
X-Ray Diffractometer	8.2	16400	60	2% on station
X-Ray Spectrometer	11.7	13130	50	2% on station
Differential Thermal Analyzer	7.4	6340	16	5% on station
Fluxgate Magnetometer	5.4	1060	1	100%
Solar Aspect Sensor	1.0	750	0.3	100%
IR Radiometer	4.0	8070	20	100%

As a result of studies providing for augmenting the basic lunar module capability, it was found that greater payload could be accommodated and increased stay times (up to three days) could be provided. With this increase in capability a mobility unit (R1A(1)E) with a more enhanced performance can be accommodated. This vehicle should accommodate a scientific payload of 75 kg with a range consistent with the three hour PLSS duration or about 12 km. The mobility unit can depend upon the shelter for recharge thus providing multiple sortie capability. A typical scientific payload is shown in Table 2-19. In addition to the reconnaissance capability, the vehicle could also be used in a basic "pack mule" function where the astronaut is replaced by 142 kg of additional payload (emplaced scientific stations) and controls the vehicle by a walking along side with a control unit.

2.4.2.2 Apollo Applications Program (R1BE, R1B(1)E)

The lunar surface mission for AAP consists of landing a LM-Shelter and combinations of payloads for a 14-day operational period; a detailed analysis of the use of vehicles on this mission has been conducted as part of the Scientific Mission Support Studies discussed above. The LSSM vehicle will be utilized in these missions. Four types of sorties will be encountered: geological/geophysical reconnaissance, shallow drilling, deep refraction seismic, and ESS emplacement. Tables 2-20, 2-21, 2-22, and 2-23 summarize the equipment carried on each sortie type. From considerations of past mission studies, Table 2-24 has been assembled to represent the worst case condition for this vehicle, since it is impossible to design for all discrete cases.

2.4.2.3 Extended Duration, One-Man Missions (R1CE, R1DE)

The scientific community has expressed a desire for a survey vehicle capable of providing operations to a larger radius (15 km) than is available with the basic LSSM vehicle and in addition provide a higher proportion of scientific experiment to driving time. The vehicle will operate on a 14-day mission in conjunction with a fixed base LM-Shelter or LM-Truck Shelter. It could also be utilized in conjunction with a more permanent extended base for shuttle or equipment transfer operations. The scientific equipment to be carried is similar to the basic LSSM mission (R1BE) Table 2-25 summarizes the mission requirements.

TABLE 2-18

SCIENTIFIC PAYLOAD R1A(1)E

	Mass (kg)
Hand Tools and Sample Containers	16.0
Surveying Staff	13.2
Gravimeter (Portable)	6.8
Magnetometer (Portable)	3.9
Sketchboard and Maps	2.3
Film Cameras	10.0
Gas Analysis Equipment	7.0
Astronaut Hazards & Nuclear Sensors	10.0
Total	69.2 kg

TABLE 2-19

TYPE 1 SORTIE GEOLOGICAL/GEOPHYSICAL RECONNAISSANCE SORTIE SCIENTIFIC EQUIPMENT

Item	Mass (kg)	Power (w)
Theodolite/Ranging Laser	22.8	20
Surveying Markers - 20	4.0	-
Sketchboard and Maps	2.3	-
Ground Truth Package	44.0	-
TV	-	25
Film Cameras - 2	-	150
Full Package	-	450
Gravimeter	6.8	6
Magnetometer	3.9	6.3
Nuclear Package	15.6	-
Spectral and Natural Gamma	-	17
Gamma-Gamma	-	-
Neutron-Neutron	-	35
Neutron-Gamma	-	25
Sample Containers	1.0	-
Surveying Staff	13.2	-
Vehicle Mounted Support	7.0	10
Hand Tools	15.0	-
*In-Situ		
Penetrometer	2.8	7
Surface Electrical	13.1	55
Radiometry	4.0	40
*Shallow Seismic Refraction		
Basic Equipment	71.0	42
Charges and Detonators	3.0	-
Gas Analysis	7.0	26
Astronaut Hazards	1.4	1.8
Data Handling and Signal Conditioning		
Displays	2	5
Multiplexers and Programmer	9	23
Cabling and Equipment Stowage	9	-
Total Mass/Sortie: 184 - 238 kg		

*One carried but not both

TABLE 2-20

TYPE 2 SORTIE DEEP REFRACTION SEISMIC SURVEY
SCIENTIFIC EQUIPMENT LIST

Item	Mass (kg)	Power (w)
Theodolite/Ranging Laser	22.8	20
Surveying Markers - 10	2.0	-
Sketchboard and Maps	2.3	-
Ground Truth Package	44.0	-
TV	-	25
Film Cameras - 2	-	150
Full Package	-	450
Gravimeter	6.8	6
Magnetometer	3.9	6.3
Nuclear Package	15.6	-
Spectral and Natural Gamma	-	17
Gamma-Gamma	-	-
Neutron-Neutron	-	35
Neutron-Gamma	-	25
Sample Containers	1.0	-
Surveying Staff	13.2	-
Vehicle Mounted Support	7.0	10
Hand Tools	15.0	-
Gas Analysis	7.0	26
Deep Refraction Seismic		
Charges and Detonators	33.1	-
Astronaut Hazards	1.4	1.8
Data Handling and Signal Conditioning		
Displays	2.0	5
Multiplexers and Programmer	9.0	23
Cabling and Equipment Stowage	9.0	-
Total Mass/Sortie:	196.0	

TABLE 2-21

TYPE 3 SORTIE DRILLING SORTIE SCIENTIFIC EQUIPMENT LIST

Item	Mass (kg)	Power (w)
Theodolite/Ranging Laser	22.8	20
Surveying Markers (10)	2.0	-
Sketchboard and Maps	2.3	-
Ground Truth Package	44.0	-
TV	-	25
Film Cameras (2)	-	150
Full Package	-	450
Gravimeter	6.8	6
Magnetometer	3.9	6.3
Nuclear Package	15.6	-
Spectral and Natural Gamma	-	17
Gamma-Gamma	-	
Neutron-Neutron	-	35
Neutron-Gamma	-	25
Sample Containers	1.0	-
Surveying Staff	13.2	-
Vehicle Mounted Support	7.0	10
Hand Tools	15.0	-
Gas Analysis	7.0	26
10-ft Core Drill	20.0	700
Core-Hole Logging Devices	8.3	10
Astronaut Hazards	1.4	1.8
Data Handling and Signal Conditioning		
Displays	2.0	5
Multiplexers and Programmer	9.0	23
Cabling and Equipment Stowage	9.0	-

Total Mass/Sortie: 190 kg

Core Samples Returned: 5 kg

TABLE 2-22

RIBE TYPE 4 SORTIE

Item	Mass (kg)
1. Equipment Permanently Attached	
Ground Truth Package	44.0
Magnetometer	
Sensor	0.23
Electronics	0.68
Orientation and Stabilization	1.0
Boom	2.0
Nuclear Package Electronics	6.0
Staff Tracking System	7.0
Data Handling and Signal Conditioning	9.0
Displays	2.0
Cabling and Equipment Stowage	9.0
Meteoroid Ejecta Detector	0.5
Tissue Equivalent Ion Chamber	0.9
Total	82.3
2. Portable Equipment Always Carried (Accessible to Surface Astronaut)	
Surveying Markers	2.0
Sketchboard and Maps	2.3
Theodolite and Ranging Laser	22.8
Gravimeter	6.8
Nuclear Sensors	
Gamma Detector	0.5
Gamma Source	1.8
Neutron Source	1.4
Neutron Detector	5.5
Spectral Gamma Detector	0.5
Sample Containers	1.0
Surveying Staff	13.2
Hand Tools Kit	15.0
Mass Spectrometer	7.0
Total	81.4
3. 10-foot Core Drill	20.0
4. ESS	136.0
Grand Total	319.7

TABLE 2-23

RIBE MISSION REQUIREMENTS

Range: 30 km/sortie

Radius: 8 km

Duration: 14 days (6 hr/sortie, one sortie/day)

No. of Stops: 20

Time on Station: 264 min

Scientific Equipment Support

Mass: 320 kg

Volume: 1 m^3

Power -

Driving: 78 w average

On Station: 228 w average; 700 w peak

Data Rate -

Driving: TV, voice, 1 channel @ 200 cps, plus 1.6 kb/sec

On Station: TV, voice, 1 channel @ 1200 cps, 2 channels @ 50 cps,
1 channel @ 200 cps, plus 1.6 kb/sec

References: Scientific Mission Support Study - Apollo Extension System, Bendix Systems Division. BSR-1207, Nov. 1965

TABLE 2-24

RICE MISSION SUMMARY

Range: 30 - 40 km/sortie

Radius: 15 km

Duration: 12 hr/sortie, at least 14 sorties total

No. of Stops: 35

Time on Station: 270 min

Scientific Equipment -

Mass: 184 - 320 kg

Volume: 0.75 - 1.0 m^3

Power -

Driving: 80 w average; 228 w peak

On Station: 100 - 300 w average; 700 w peak

Data Rate -

Driving: TV, voice, 1 channel @ 200 cps, plus 1.6 kb/sec

On Station: TV, voice, 1 channel @ 1200 cps, 2 channels @ 50 cps, 1 channel @ 200 cps, plus 1.6 kb/sec

Ingress/Egress Cycles: 35 - 40

EVA Time: 4 hr

As a result of further considerations of the 12-hour mission, NASA recommended that a new mission be introduced which provides a larger increase in the one-man mission capability to provide for 48 hours duration. The specific mission for this vehicle would be similar to the LSSM type of mission (i. e. similar scientific equipment); however, the range capability would allow exploration to about a 50 km radius around a fixed shelter. Table 2-26 summarizes the mission requirements for this vehicle as obtained from NASA.

2.4.3 Two-Man Crew Missions

2.4.3.1 LM-Shelter Base Operation with a Two-Man Vehicle (R2AE)

A mission similar to the AAP lunar surface mission could be carried out allowing the crew to be operating simultaneously in extra vehicular activities. This would permit more efficient scientific data gathering during a traverse especially with regard to geologic mapping. In this case the scientific equipment cargo is traded off against the additional crew member in the basic LSSM design. In addition the vehicle should be fitted for normal operation with two-men. The basic scientific mission would remain similar to R1BE with less extensive scientific equipment carried. Table 2-27 summarized the mission requirements and Table 2-28 is the scientific equipment list.

TABLE 2-25

R1DE, EXTENDED RANGE ONE-MAN VEHICLE
MISSION REQUIREMENTS

Duration:	14 days consisting of three, 48-hr sorties and three, 8-hr sorties
Range:	75-125 km/48-hr sortie 40 km/8-hr sortie
Mobility Duty Cycle:	50 to 70 percent
Payload:	320 kg similar to R1BE payload
Crew Size:	One man primary plus second man in lieu of payload, carried externally

TABLE 2-26

R2AE MISSION SUMMARY

Range: 20 - 30 km

Radius: 8 km

Duration: 6 hr

No. of Stops: 20

Time on Station: 180 min

Scientific Equipment -

- Mass: 153 kg
- Power -
  - Driving: 70 w average
  - On Station: 140 w average
- Energy: 630 w-hr/sortie

Data Rate -

- Driving: TV, voice, plus 1.6 kb/sec
- On Station: TV, Voice, 1.6 kb/sec, 2 channels @ 50 cps, plus 1 channel @ 1200 cps

TABLE 2-27

R2AE SCIENTIFIC EQUIPMENT LIST

Item	Mass (kg)
1. Equipment Permanently Attached	
Ground Truth Package	44.0
Nuclear Package Electronics	6.0
Staff Tracking System	7.0
Data Handling and Signal Conditioning	9.0
Displays	2.0
Cabling and Equipment Stowage	9.0
Meteoroid Ejecta Detector	0.5
Tissue Equivalent Ion Chamber	0.9
Total	78.4
2. Portable Equipment Always Carried (Accessible to Surface Astronaut)	
Surveying Markers	2.0
Sketchboard and Maps	2.3
Theodolite and Ranging Laser	22.8
Gravimeter	6.8
Nuclear Sensors	
Gamma Detector	0.5
Gamma Source	1.8
Neutron Source	1.4
Neutron Detector	5.5
Spectral Gamma Detector	0.5
Sample Containers	1.0
Surveying Staff	13.2
Hand Tools Kit	15.0
Total	74.4
Grand Total	

2.4.4.2 Long Range Traverse Mobile Laboratory (R3BE)

This mission is designed to obtain geological information on an inter-regional or provincial domain. The total range is 1600 km in a long, linear traverse across a highly differentiated or active area. This range could be accomplished in two pieces of 800 km (return to start), or a long traverse with the crew pick up for return to earth at the end of the traverse. A number of geological and geophysical instruments have been recommended, as well as the capability for transporting a number of selfcontained emplaced stations for distribution over the surface during the traverse. Crew size is recommended at a minimum three men so that sufficient scientific time is available. Table 2-34 summarizes the mission requirements and Table 2-35 contains estimates of the recommended scientific package.

2.4.4.3 Standard Mobile Laboratory Traverse (R3CE)

To increase available time for scientific operations during a 14 day mobile laboratory traverse, a three man crew may be accommodated in the basic vehicle. This will increase the scientific man hours available by approximately 50-60%. The scientific equipment to be carried will be identical to the mobile laboratory payload summarized in Table 2-29.

2.4.4.4 Very Long Range Traverses (R3DE)

The MIMOSA scientific programs which are in the process of being generated, have identified geophysical profiles or "paths" extending across regional geologic barriers for ranges in excess of 3000 km. To obtain such ranges and provide sufficient scientific time, a three man, 90-day duration vehicle is recommended. The scientific payload to be accommodated is approximately 1500 kg and is similar to that shown for the 42-day mission summarized in Table 2-35. It is unknown at this time whether the extended duration mission would necessitate crew rotation during performance of the basic mission. The MIMOSA studies will perform the necessary logistics studies required to determine the techniques for accomplishing this mission.

TABLE 2-33

SCIENTIFIC INSTRUMENTS FOR R3AE

Instrument	Weight (kg)
Module 1. Lunar Field Work (Astronaut Kit)	
1. Geological field tools, instruments	20
2. Surveying, charting, and mapping instruments	6
3. Polaroid camera and accessories	4
4. Optical telescope and accessories	6
5. Petrographic microscope and accessories	2
6. Simple hand spectroscope and microscope	2
7. Gas gun (pneumatic ejector)	5
Module 2. Lunar Topography - Geology	
1. Polaroid and conventional camera and accessories (astronaut operated)	4
2. TV cameras	17
3. Color TV or Uvicon camera	15
4. Optical telescope (astronaut-operated)	8
5. Lunar facsimile instrument	20
6. Theodolite and accessories	6
7. Soil mechanics instruments	
a. Spacecraft jack and accessories	10
b. Impacting sphere equipment	80
c. Friction disc and impeller	2
8. Drill (30 meter depth)	90
9. Portable astronaut drill	6
10. Surface and subsurface probes	40
11. Deep subsurface probes (AVCO)	35
12. Lunar dust measurement instruments	19
Module 3. Lunar Meteorite and Radiation Environment	
1. Meteorite spectrometer (primaries and secondaries)	15
2. Charged particle spectrometer	13
3. Neutron spectrometer	5
4. Solar plasma spectrometer	10
Module 4. Lunar Geophysics-Geochemistry	
1. Seismometry (passive)	10
2. Refraction seismometry	10
3. Gravimeter	1
4. Lunar surface and subsurface geophysical probes	
a. Gamma-ray backscatter apparatus	3
b. Surveyor-type surface and subsurface geophysical probes	40
c. Deep subsurface probes (AVCO)	14
d. Penetration accelerometers	3
5. Spectrometers (visible, ultraviolet, infrared)	7
6. X-ray diffractometer	15
7. X-ray fluorescence spectrometer	19
8. Laue X-ray diffractometer	25
9. Alpha particle scattering spectrometer	4
10. Mass-ion spectrometer and excitor	16
11. Neutron scattering hydrogen detector	2
12. Neutron-gamma ray instrument	10
13. Gamma-ray scintillation K-40 detector	8
14. Ion Current gauge	2
15. Gas pressure gauge	10
16. Electric field meters and magnetometers	4
Module 5. Lunar Biology	
1. Gas chromatograph	6
2. Spectrometers	6
3. Sample containers	15
Total Mass Modules 1 - 5	680

TABLE 2-34

MISSION SUMMARY R3BE

Range: 1600 km
Radius: Linear or 800 km
No. of Stops: 80
Time on Station: 400 hr
Scientific Equipment -
Mass: 1500 kg (includes 750 kg of ESS to be off-loaded and replaced by geological samples)
Volume: 1 m^3 internal; 3 m^3 external plus 3-m drill
Power -
Driving: 225 w average
On Station: 500 w average: 1.2 kw peak
Data Rate -
Driving: TV, voice, plus 15 kb/sec
On Station: TV, voice, plus 51.2 kb/sec
Ingress/Egress Cycles: 56
EVA Time: 330 man-hr

TABLE 2-35

R3BE SCIENTIFIC EQUIPMENT LIST

Description	Mass (kg)
Hand tools and sample containers	150
Mechanical sample collector	150
Analytical laboratory equipment	150
Active seismic	130
Magnetometer	15
Gravity survey	20
In situ measurements	20
Radiation measurements	20
Ground truth package	55
3-meter core drill (used in place of recommended trenching device)	40
9-Emplaced Scientific packages @ 83 kg	750
Total	1500 kg

2.4.5 Four-Man Crew Missions

2.4.5.1 Maximum Exploration Mobility Mission (R4AE)

At the start of the program, the maximal mission requirements were determined by the maximum range requirement which was set at 2000 km. This distance is sufficient for a traverse across a major geological area 1000 km in extent and return, or for a single linear traverse of 2000 km to determine the geological significance and extent of a stratigraphic contact, such as that between the Appenine Mountains and the Mare Imbrium. Crew size was set at four so that mission duration would not be excessive and, yet, there would be enough time allocated to scientific tasks. This is also compatible with the delivery by two unmodified LM-Taxis. The scientific payload was set at 1500 kg in accordance with the recommendations of the NASA Conference on Lunar Exploration and Science (July 1965) and is similar to R3BE. Mission duration is based on an expected average mission speed of 5 km/hour, or 400 hours to traverse 2000 km, plus 400 hours for scientific activities plus 400 hours for non-operational activities. An additional six days for unloading, storage and contingency brings total mission time to 56 days. The maximum gross mass allowable is 12, 800 kg, the payload limit of the LLV delivery vehicle. Table 2-36 summarizes the mission characteristics.

As a result of crew delivery system analyses performed in the MIMOSA study, it was recommended that further consideration of this mission be dropped since the crew delivery modes provide for accommodation of crews in multiples of three men.

2.5 OPERATIONAL PROFILES

To establish the driving and work time availability for various missions, operational profiles were established considering crew levels varying from two to four men. These profiles are applicable only to mobile laboratories where the vehicle supplies the primary life support means.

Table 2-37 shows the profile for a two man crew. Considering the requirements for rest and personal time, approximately five hours per day will be available for driving, and about 14-man-hours per day will be devoted to extravehicular activities and laboratory work.

TABLE 2-36

MISSION SUMMARY R4AE

Range: 2000 km
Radius: Linear or 1000 km
Duration: 56 days
No. of Stops: 100
Time on Station: 800 hr
Scientific Equipment -
Mass: 1500 kg (includes 750 kg of ESS)
Volume: 1 m^3 internal; 4 m^3 external
Power -
Driving: 225 w average
On Station: 500 w average; 1.2 kw peak
Data Rate -
Driving: TV, voice, plus 15 kb/sec
On Station: TV, voice, plus 51.2 kb/sec
Ingress/Egress Cycles: 64
EVA Time: 360 man-hr

TABLE 2-37

OPERATIONAL PROFILE
TWO-MAN CREW

ASTRONAUT

	A	B
1:00	Eat and Rest	Same
2:00		
3:00		
4:00		
5:00		
6:00	Rest	Same
7:00		
8:00		
9:00		
10:00	Eat and Hygiene	Same
11:00		Monitor EVA
12:00	EVA	and
13:00		Work In
14:00		
15:00	Eat and Rest	Same
16:00		Navigate and
17:00	Drive	Systems Monitor
18:00		
19:00		
20:00	Eat and Rest	Same
21:00	Drive	Navigate
22:00		
23:00	Work	Work
24:00	In	In

Table 2-39 shows the profile for a three-man crew. For these vehicles the driving time available increases to six hours and the scientific work time is approximately 18 man-hours. With the additional crew, it is also possible to permit two astronauts to work on the surface simultaneously.

The four man operational profile, shown in Table 2-40, allows seven hours per day of driving time and 28 man-hours per day of scientific activities. These missions also permit two astronauts to participate in simultaneous extra vehicular activities.

TABLE 2-38

OPERATIONAL PROFILE
THREE-MAN CREW

	ASTRONAUT A	ASTRONAUT B	ASTRONAUT C
1:00	Drive	Navigate	Systems Monitor and Communications
2:00			
3:00			
4:00			
5:00	Eat and Rest	Same	Same
6:00			
7:00	EVA	EVA	Monitor EVA and Work In
8:00			
9:00			
10:00	Eat and Rest	Same	Same
11:00			
12:00	Navigate	Drive	Systems Monitor and Communications
13:00			
14:00	Work In	Eat and Rest	Work In
15:00			
16:00	Eat and Rest		Eat and Rest
17:00			
18:00		Rest	
19:00			
20:00	Rest		Rest
21:00			
22:00		Eat and Hygiene	
23:00			
24:00	Eat and Hygiene	Work In	Eat and Hygiene

TABLE 2-39

OPERATIONAL PROFILE
FOUR-MAN CREW

<table>
<tr><th></th><th colspan="4">ASTRONAUT</th></tr>
<tr><th></th><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>1:00</td><td rowspan="7">Rest</td><td rowspan="7">Rest</td><td>Eat & Hygiene</td><td>Eat & Hygiene</td></tr>
<tr><td>2:00</td><td rowspan="4">EVA</td><td rowspan="4">Monitor EVA and Work In</td></tr>
<tr><td>3:00</td></tr>
<tr><td>4:00</td></tr>
<tr><td>5:00</td></tr>
<tr><td>6:00</td><td>Eat & Rest</td><td>Eat & Rest</td></tr>
<tr><td>7:00</td><td rowspan="2">Work In</td><td rowspan="2">Work In</td></tr>
<tr><td>8:00</td><td>Eat & Hygiene</td><td>Eat & Hygiene</td></tr>
<tr><td>9:00</td><td rowspan="4">Drive</td><td rowspan="4">Navigate</td><td rowspan="4">Systems Monitor</td><td rowspan="4">Communication</td></tr>
<tr><td>10:00</td></tr>
<tr><td>11:00</td></tr>
<tr><td>12:00</td></tr>
<tr><td>13:00</td><td>Eat & Rest</td><td>Eat & Rest</td><td>Eat & Rest</td><td>Eat & Rest</td></tr>
<tr><td>14:00</td><td rowspan="3">Navigate</td><td rowspan="3">Drive</td><td rowspan="3">Systems Monitor</td><td rowspan="3">Communication</td></tr>
<tr><td>15:00</td></tr>
<tr><td>16:00</td></tr>
<tr><td>17:00</td><td rowspan="4">EVA</td><td rowspan="4">Monitor EVA and Work In</td><td>Work In</td><td>Work In</td></tr>
<tr><td>18:00</td><td rowspan="7">Rest</td><td rowspan="7">Rest</td></tr>
<tr><td>19:00</td></tr>
<tr><td>20:00</td></tr>
<tr><td>21:00</td><td>Eat & Rest</td><td>Eat & Rest</td></tr>
<tr><td>22:00</td><td rowspan="3">Work In</td><td rowspan="3">Work In</td></tr>
<tr><td>23:00</td></tr>
<tr><td>24:00</td></tr>
</table>

SECTION 3

MISSION REQUIREMENTS SPECTRUM FOR BASE SUPPORT VEHICLES

A lunar base is a shelter complex which serves as a place from which multiple lunar missions are to be performed. This base is expected to have an operational period which is greater than the expected staytime of a single crew. Therefore, the operational duration of the base is designated as being from long tern to quasi-permanent. A shelter such as the LM around which exploratory operations are performed is not considered as a lunar base since it is of short operational duration and is not subject to re-activation. Only one set of lunar base concepts has been investigated in detail to date; namely, LESA. The vehicular requirements for base support have been obtained from the LESA studies.

A variety of vehicular tasks must be performed for the deployment and operation of a lunar base. It is the objective here to develop a spectrum of base support mission requirements and to evaluate some base support vehicle system concepts to determine mobility gaps presently not filled by existing concepts.

3.1 SUMMARY OF REQUIREMENTS

A vehicle may be constructed as a single frame vehicle, a multiple frame vehicle or a modular vehicle. A single frame vehicle will be classified as a prime mover; that is, a vehicle which carries the primary source of power and mobility control. A multiple frame vehicle has a prime mover and a trailer. The modular vehicle has modular modification kits for appendages which are attached to a prime mover or trailer in order to accomplish a specific task. The vehicle concepts are synthesized from combinations of the following: (1) Prime Movers (work capability is described by drawbar pull), (2) Trailers (capacity is specified by the load capability), and (3) Appendages (specific attachments such as backhoe, bucket, blades or highlifts). This classification has previously been employed in LRV studies. Within these classifications the vehicle can be described by the remaining vehicle requirements: crew size, payload, range, duration, duty cycle, draw bar pull, life and appendages.

The derivation of base support requirements and vehicle systems is incorporated in Sections 3.2 and 3.3. The base support requirements spectrum is summarized here according to the above vehicle concept classification. The underlying philosophy adopted by MOBEV is to derive Base Support Vehicles from earlier exploration vehicles, to the maximum extent possible. This approach is feasible since base operations (which are predicated on a Lunar Logistic Vehicle delivery system) will be time-phased to follow the earlier mobile laboratory (LM/Truck) and Shelter (LM/Shelter, LM/Truck, etc.) modes of operation. The study of LESA requirements and plausible variations resulted in the identification of an initial spectrum consisting of three trailers (R0AB, R0BB, and R0CB), and five prime movers (R1AB, R1BB, R1CB, R2AB, and R2CB). All trailers and four of the five prime movers are derivatives of earlier exploration vehicles. This initial spectrum and the nomenclature code are summarized in Table 3-1.

Further analysis resulted in the following changes to the initial spectrum. For the base support spectrum, the R1CB vehicle was retained as a unique vehicle while the trailer derivatives (R0AB, R0BB, and R0CB) and the other prime movers, (R1AB, R1BB, and R2BB) were placed in a secondary category because of their being generated from basic roving vehicles previously categorized as exploration vehicles. The R2AB prime mover has been dropped from the spectrum since it is a derivative of the 8-day (LESA) MOLAB vehicle, R2BE, which has been eliminated from the exploration vehicle spectrum. Table 3-2 lists the appendages which can be utilized with the prime movers.

3.2 BASE SUPPORT MISSION REQUIREMENTS

From the LESA studies, References 9 and 16, a summary of base support tasks has been organized into functional categories as indicated in Table 3-3. For the functional classification of personnel transport, the requirement can be satisfied by exploration prime movers. Surface modification tasks are itemized with a type of construction equipment which could adequately perform the task. A vehicle may be required to serve as a temporary shelter during emergency and constructional periods. This task is indicated in a fourth functional area. Other functional tasks are grouped into a miscellaneous category.

TABLE 3-1

LRV REQUIREMENTS SPECTRUM (R), BASE SUPPORT (B)

	A	B	C	D
0 Unmanned (Trailers)				
Payload	600 kg	2500 kg	6500 kg	
Range/Trip	10 km	10 km	10 km	
Trips/Month	6	4	2	
Duration	N/A	N/A	N/A	
Appendages	-	-	-	
Draw Bar Pull	N/A	N/A	N/A	
Life	2 years	2 years	2 years	
1 One-Man (Prime Mover)				
Payload	320 kg	320 kg	N/A	
Range/Trip	35 km	40-125 km	10 km	
Trips/Month	30	30	30	
Duration	6 hr	8-48 hr	6 hr	
Appendages	*	*	**	
Draw Bar Pull	150 lb	200 lb	1000 lb	
Life	2 years	2 years	2 years	
2 Two-Man (Prime Mover)				
Payload	320 kg	320 kg		
Range/Trip	250 km	400 km		
Trips/Month	N/A	N/A		
Duration	8 days	14 days		
Appendages	*	*		
Draw Bar Pull	600 lb	600 lb		
Life	2 years	2 years		

* Backhoe and Towing Hitch and Winch

** Bulldozer Blade, Backhoe, Clam-Shell Bucket, Towing Hitch and Winch

Nomenclature Code
(Letter-Number-Letter (Number)-Letter(s))

Digit 1 Letter R or F for Rover or Flyer, respectively
Digit 2 Number representing nominal crew size
Digit 3 Letter representing nominal mission capability
Digit 4 Number in parenthesis used where alternate vehicle concepts exist for a particular nominal mission requirement
Digit 5 Letters E, B, and R representing Exploration, Base Support, and Rescue type vehicles.

TABLE 3-2

APPENDAGES

MODULAR UNITS ATTACHED TO PRIME MOVERS
Backhoe
Crane
Towing Hitch
Winch
Clam-Shell Bucket
Bulldozer/Grader Blade

The LESA studies have postulated development of a large operational base which has evolved from smaller bases. This evolution occurs in four steps beginning with the initial base, base model 1, and ending with base model 4. Each step is also considered an independent base in itself. The support requirements are different for each model because there are different mission requirements. Base 1 as part of an evolutionary build-up is concerned with establishing the feasibility of base operations, whereas base 3 requirements include preparations for base 4. These base support vehicular requirements are presented in Table 3-4 for each base according to the three main functional categories. The requirements of base 4 are similar to base 3 and are not repeated in this table.

3.3 BASE SUPPORT SYSTEM CONCEPTS

There are five vehicle parameters related to the missions for exploration vehicles: (1) vehicle function, (2) crew size, (3) range, (4) duration (not including pre-mission storage time), and (5) payload. Base support vehicles are subject to many functional requirements.

The tasks generally belong to one of the three following functions: (1) personnel transport, (these also have the capacity for personal effects and a small cargo allotment), (2) material handling and transporters (these

TABLE 3-3

POTENTIAL SURFACE VEHICLE TASKS

1.	Personnel Transport Local site trips Remote site crew rotation
2.	Surface Modification and Construction Bull: excavation, embankment, clearing and grading Bucket loader: excavation, embankment, clearing and grading Dragline: excavation and embankment Crane and clamshell bucket: excavation, embankment and clearing Power shovel: excavation, embankment and long haul Scraper: excavation, embankment and long haul Rooter: excavation Rotary brush and collector: excavation and embankment Winch: clearing and emergencies Roller, weighted vehicle, vibrator and tamper: soil compaction Chemical spray, flame thrower and solar concentrator: soil stabilization Drill, auger, full face boring machine, mucker: underground operations, mining, drill/blast Manipulator: small miscellaneous and hazardous tasks Crane: shelters and miscellaneous structure erection Combined basic units: all tasks
3.	Material Handling Loading and unloading (cargo vehicles and miscellaneous modules): crane, outriggers, hold-down devices, etc. Transport (entire vehicles, modules, miscellaneous cargo): crane, trailer, external storage
4.	Personnel Shelter Temporary living quarters: at remote locations and/or during construction periods Emergency: against micro-meteorite bombardment and during periods of high solar activity
5.	Miscellaneous Portable power source for remote operations, particularly during construction

include both horizontal and vertical cargo carriers such as trucks and cranes respectively), (3) surface modification and construction equipment such as surface graders, cranes, and shovels. The base support vehicular requirements are classified into these functional areas. Each category has been examined for vehicle systems which fulfill the base support requirements.

Prime mover requirements for the functions of personnel transport and material handling of Table 3-1 are adequately satisfied by the exploration vehicle concepts as presented in Table 3-5. For the construction function, many of the requirements are satisfied by appendages to the prime movers of the exploration vehicles. However, for surface grading and leveling tasks, a new prime mover concept is required. This is a high-powered prime mover; identified as concept R1CB of Table 3-1. Its requirement is for a highly tractive vehicle with a bulldozer grader blade, backhoe, clam-shell bucket, towing hitch and winch attachments. A one-man crew is located in a protective shelter utilizing backpack life support. The duty cycle is anticipated to be 6 hr/day.

The trailer systems contained in Table 3-1, can be derivatives of one-, two-, and three-man exploration rovers. The duration and range can be calculated from the number of trips that will be required at a lunar base. Resupply of the base provides the major trip requirements upon material handling vehicles. Two earth launch vehicle systems have been assumed for cargo delivery; namely, Saturn V-LLV and Saturn 1B, having respective payloads of 11,500 kg and 705 kg. An estimate of the trip requirements to unload a single supply launch vehicle is given in Table 3-6 for both launch systems. Changes in crew personnel and other lunar surface payload requirements are within the Saturn 1B class and are so indicated in Table 3-6 The duty cycle of the trailer is the average number of trips per month to perform the unloading operation as determined from the estimated number of launch vehicles.

The powered trailer spectrum is presented in Table 3-7. Modifications of these trailer concepts can be performed in order to incorporate the other vehicular functions that a trailer may serve. These variations are also presented in Table 3-7.

The appendages to the prime mover, shown in Table 3-2, are primarily to perform surface modification, construction, and material handling functions.

TABLE 3-4

VEHICLE BASE SUPPORT REQUIREMENTS

Personnel Transport	Surface Modification and Construction	Material Handling
Base 1 3 men, 1.6 km, 6 hr 2 men, 6.6 km, 12 hr		1. Solar array 28 panels, total volume, 6' x 2' x 2', 200 kg 2. Thermal radiator 16 panels, total volume, 6' x 2' x 2.5' Total range = 2.0 km Total duration = 8 hr
Base 2 3 men, 2 km, 6 hr 2 men, 25 km, 36 hr	1. Soil collection, 500 ft^3 of soil 550 kg, 180 ft^3 soil box, 10 ft^3 loader. Ability to place soil 42.5' at elevation. Total range = 5 km Total duration = 32 hr	1. Fuel transfer, 4100 kg, 115" diameter 2. Solar array and radiator, 56 panels 6' x 2' x 4', 400 kg, 13 panels 6' x 2' x 2', 120 kg 3. Transfer supplies 550 kg Total range = 48 km Total duration = 64 hr
Base 3 2 men, 9.0 km, 6 hr 3 men, 3.5 km, 6 hr 4 men, 3.5 km, 6 hr	1. Soil collection, 500 ft^3 soil 550 kg, 180 ft^3 soil box, 10 ft^3 loader. Ability to place soil 42.5' elevation. 2. Prepare holes for reactors, 3 are required, 14' deep, 4' diameter Total range = 20 km Total duration = 55 hr 3. Prepare shelter foundations, shelter level less than 2°	1. Fuel transfer, 5500 kg 2. Solar array, 28 panels, 6' x 2' x 2', 200 kg 3. Portable power supply, 2500 kg 4. Deploy tunnel, 260 kg 5. Transport supplies, 550 kg 6. Offload and transport reactor, 6500 kg 7. Power line setup, 650 kg 8. Set up thermal radiator, 48 panels, 6' x 2' x 7.5' Total range = 80 km Total duration = 165 km

TABLE 3-5

EXISTING VEHICLE CONCEPTS CORRESPONDING TO BASE SUPPORT PRIME MOVERS REQUIREMENTS

Nomenclature in Table 3-1	Applicable Existing Design or Concepts
R1AB	LSSM One Man
R1BB	LSSM With Cabin
R2AB, R2BB	MOLAB

TABLE 3-6

TRAILER TRIP REQUIREMENTS

Trailer Derivative	*Trips per Saturn V-LLV	Trips per Saturn-IB, Crew Delivery, Local	Duty Cycle Average Trips per Month
LSSM Trailer (R0AB)	20	2	6
MOLAB Trailer (R0BB)	6	1	4
MOBEX Trailer (R0CB)	3	1	2

* Trip limitations are based on payload mass for the LSSM trailer, and on payload mass and package sizes for the MOLAB and MOBEX trailers.

TABLE 3-7

POWERED TRAILER SPECTRUM

Trailer (Derivative)	Cargo Capacity (kg)	Range per Trip (km)	Duty Cycle (trip/mo)	Life (yr)	Trailer Bed Size (ft x ft)	Potential Modification and Mission Variations
R0AB (LSSM)	620	10	6	2	20 x 20	(2) (3)
R0BB (MOLAB)	2500	10	4	2	-	(1) (2) (3)
R0CB (MOBEX)	7000	10	2	2	-	(1) (2) (3)

Potential Modifications and Mission Variations

1. Retrieval of disabled exploration vehicle (radius of action is a function of prime mover)
2. Personnel transfer (4 men-10 km range/trip - no cabin)
3. Addition of driver station with self contained power supply, and base support appendages or extended scientific capability.

SECTION 4

MISSION REQUIREMENTS SPECTRUM FOR FLYING VEHICLES

The Lunar Flying Vehicle offers significant advantages as a mode of travel from point to point on the lunar surface, though at the expense of reduced range. The advantages are derivable from the speed of travel and the fact that the destination is independent of the intervening terrain.

4.1 SUMMARY OF REQUIREMENTS

Flying vehicles have been considered for manned surface missions at all stages of the exploration program requiring travel beyond the immediate vicinity of the landing point. LFV missions can be classified as exploration or rescue. A special category of rescue missions is the return of the astronaut crew to lunar orbit for cases in which the primary return vehicle is inoperable.

The requirements spectrum for Lunar Flying Vehicles is summarized in Table 4-1. Vehicle parameters are independent of whether the purpose of the sortie is exploration or rescue. The table shows nominal values of maximum range for a single trip, based on a sortie duration of three hours and no payload. Sortie duration may be increased to six hours by adding spare PLSS's at 29 kg each. Scientific equipment or other payload may be substituted for crew members at 140 kg of cargo per astronaut. Small excesses of payload weight can be accommodated by a reduction in range. Minimum crew size is one, and all LFV's can be operated by a single astronaut.

TABLE 4-1

LUNAR FLYING VEHICLE REQUIREMENTS SPECTRUM

	A	B	C	D	E
1-Man Crew					
Range*	8 km	20 km	130 km		
Payload	0	0	0		
2-Man Crew					
Range	20 km	50 km	100 km	200 km	LOR
Payload**	0	0	0	0	0
3-Man Crew					
Range	50 km	200 km	400 km	800 km	LOR
Payload**	0	0	0	0	0
4-Man Crew					
Range	1000 km				
Payload	0				

* Maximum range for single flight.

** Payload mass may be increased 140 kg for each astronaut eliminated from the crew. Minimum crew size is one man.

Note: Range is calculated on the basis of one PLSS per crew member. Sortie duration is three hours for maximum crew size, and may be increased to six hours by carrying one extra PLSS per crew member.

Nomenclature Code: (Letter-Number-Letter)

1. First Letter: F for flying vehicle
2. Number: Maximum crew size
3. Second Letter: Relative mission capability for vehicles of a particular crew size.

Vehicle conceptual designs for each concept, with the exception of the four-man crew vehicle, are provided in other volumes of this report and in the accompanying MOBEV Data Books. The four-man vehicle was dropped from consideration early in the study since the four-man crew violates a MOBEV Program constraint.

4.2 LUNAR FLYING VEHICLE MISSION REQUIREMENTS

Missions for Lunar Flying Vehicles are undertaken primarily for one of two purposes, rescue or exploration. Exploration vehicles may generally be used for rescue whenever astronaut survival takes priority over exploration. Rescue vehicles are not generally used for exploration alternatives. However, when flyers are used for exploration in conjunction with other vehicles, flyers which are on standby for rescue at one point may be used for exploration at another.

The mission requirements spectrum for LFVs is shown in Table 4-2, classified according to whether the primary purpose is rescue or exploration. Within these two categories, mission concepts are classified according to the exploration concept for which the vehicle is designed. Missions are described in the following sections. Paragraph numbers correspond to identification numbers in Table 4-2.

4.2.1 Rescue Mission Concepts Utilizing the LM-Shelter

The LM-Shelter is used in combination with several vehicle types. A number of Shelter concepts have also been postulated for use in conjunction with a LM-Truck. These may also be used in combination with various vehicles.

Early concepts will probably utilize a two-man crew on a 14-day staytime mission. A rescue concept involves provision of a flying vehicle capable of returning the two-men to lunar orbit rendezvous with the Apollo CSM for earth return.

A concept with a minimum roving vehicle capable of operating to 5 km radius was postulated. A small flyer capable of being packaged and loaded on the small rover is required. It should provide one-way transportation for one astronaut for a distance of 5 km.

TABLE 4-2

MISSION REQUIREMENTS SPECTRUM FOR LUNAR FLYING VEHICLES

Design Points (See Figure 4-1)	Basic Mission Concepts	Range	No. of Flights	Crew Size	Payload (kg)	Selected Design Points (See Table 4-1)
	RESCUE					
	Station:					
	1 (LM-Shelter)	LOR	1	2	-	F 2 E
	2 (LM-Shelter)	5	1	1	-	R 1 A
A	3 (LM-Shelter)	8	1	1	-	F 1 A
B	4 (LM-Shelter)	8	2	1 & 2	-	F 2 B
C	5 (LM-Shelter)	8	1	2	-	***
	6 (LM-T-Shelter)	LOR	1	3	-	F 3 E
E, F	7 (LM-T-Shelter)	15	1	1 or 2	-	F 1 B, F 2 A
G, H	8 (LM-T-Shelter)	15	2	1 & 3	-	F 2 C
	Mobile Laboratories:					
L, D	1 (LM-Truck)	80	1	2	-	F 2 C
K, I	2 (LLV)	400-800	1	3	-	F 3 C, F 3 D
	3 (LLV)	1000	1	4	-	F 4 A
	Base:					
J	1 (LLV)	120-160	1	2	-	F 2 D
	EXPLORATION					
	Station:					
N	1 (LM-Shelter)	6	4	1	135	F 2 A
O	2 (LM-Shelter)	8	6	1	165	F 2 B
P	3 (LM-T-Shelter)	50	6	2	100	F 2 D
	Mobile Laboratories:					
Q	1 (LM-Truck)*	Varies	Varies	1	25	F 1 C
Q	2 (LLV)**	Varies	Varies	1	25	F 1 C
	Base:					
R	1 (LLV)	15	12	2	150	F 3 A, F 3 B****

* Use for exploration as rescue requirements decrease

** Forward reconnaissance scout

*** Drop in favor of two F 1 A

****Reduce range requirement to 12 km

An advanced vehicle for use with the LM-Shelter, capable of operation to 8 km is desired. The flying vehicle could be packaged for carrying on the vehicle and returning one man 8 km to the Shelter.

An alternative concept involves keeping a flyer at the Shelter, and conducting the rescue from that point. The requirements are that the vehicle fly out to 8 km with one man and return 8 km with two men.

For concepts involving normal use of a roving vehicle with two men, a flyer providing return capability to the Shelter (8 km) with the two men is required. This vehicle should be capable of being packaged for carrying on board the roving vehicle.

The LM-Shelter-Truck concepts may be utilized with a maximum crew of three men. A flying vehicle providing capability of returning three men to lunar orbit rendezvous with the Apollo CSM is required.

A surface vehicle capable of a 15 km operating radius with one or two men is needed. A flying vehicle for rescue may be carried on the vehicle to return the men 15 km.

A surface vehicle is required having a 15 km operating radius, to be located at the Shelter and fly out 15 km with one man, and return 15 km with two or three men.

4.2.2 Rescue Missions, Mobile Laboratory Concepts

A mobile laboratory with a two-man crew, an 80 km radius of operations, and 400 km total traverse is landed by a LM-Truck. A flying vehicle capable of returning two men 80 km is required. It should be capable of being packaged for carrying aboard the mobile laboratory.

A surface vehicle capable of long linear traverses (not constrained to return to the starting point) of 1600 km range has been postulated. A cache may be located 21 days out at 800 km. The vehicle will carry a crew of three men. A flyer should be provided, which may be packaged on the mobile laboratory, which will carry the crew of three men a distance of 400 to 800 km. Feasibility of this concept requires a detailed examination of the total logistics problems involved.

As a limiting case to the mission spectrum for the 1970-1980 time period, a mission was postulated based on the recommendations of the NASA 1965 Summer Conference on Lunar Exploration and Science, held at Falmonth, Massachusetts. The maximal mission calls for a traverse of 2000 km, with no constraint to return to the landing point. Crew size is four. A flying vehicle to be carried on the rover capable of transporting four men 1000 km is needed.

This requirement was excluded from the subsequent analysis, since crew size for LFV's is limited to three men by the study guidelines of the Statement of Work.

4.2.3 Rescue Missions, Permanent Base Concepts

Roving vehicles will be provided with an action radius of 120-160 km and a crew of two. A flyer carried on the roving vehicle, capable of returning the crew 120-160 km to the base site may be required.

4.2.4 Exploration Mission Concepts Utilizing the LM-Shelter as a Station

LM-Shelter concepts may require use of a single flyer for exploration, or a flyer and a roving vehicle. The third mission concept is a Shelter on an LM-Truck with a separate mobility payload.

A vehicle is required with a capability of two sorties to 6 km radius, with a crew of one and a payload of 135 kg.

A vehicle is needed with a three-sortie capability to 8 km radius, with a crew of one and a payload of 165 kg. This is required for deployment of satellite ESS stations for the expanded ESS concept. The feasibility of refueling between sorties should be investigated.

A vehicle is required with a capability of three sorties to 50 km range, with a crew of two and a payload of 100 kg. This concept is particularly useful for investigating specific features such as the Straight Wall or the central peak wall and crater rim of Alphonsus.

4.2.5 Exploration Missions, Mobile Laboratory Concepts

The basic rescue flyer provided for mobile laboratory concepts can be adapted for use as an exploration vehicle when emergency return requirements decrease during a traverse.

A scout vehicle is needed for reconnaissance of forward areas, possibly a one man vehicle with multiple refueling capability. A payload of 25 kg for photography and remote sensing is required.

4.2.6 Exploration Missions, Permanent Base Concepts

A vehicle is needed with a capability of six sorties to a radius of 15 km, carrying a crew of two men and a payload of 150 kg to be used for exploration of specific features about the base site which require longer stay times, or which are inaccessible to surface vehicles.

4.3 LFV SYSTEM CONCEPTS

A parametric analysis of the mission requirements spectrum was performed. Results are shown in Figure 4-1. Design points satisfying the mission spectrum have been derived as well as the related curves showing variations in ΔV as a function of payload plus crew weight. Letters identifying design points appear in the first column of Table 4-2, indicating the corresponding mission concept.

A further analysis was conducted to determine the feasibility of utilizing the MIMOSA design points in the MOBEV vehicle requirements spectrum. MIMOSA design points are indicated in Table 4-1 by crosses. The corresponding ΔV curves are also shown. The result of the analysis was the adoption of the MIMOSA design points augmented by three new design points. The resulting vehicle spectrum is shown in Table 4-1. The vehicle design points which meet the requirements in the mission requirements spectrum are indicated in the last column of Table 4-2.

LFV concepts have been developed to meet requirements for two missions, emergency return from the MOLAB and exploration as part of the Apollo Extension Systems study.

4.3.1 Apollo Logistics Support System (ALSS)

An LFV has been developed to perform rescue missions during the MOLAB traverse described in Section 2.2.2.2. Vehicle characteristics are summarized in Table 4-3.

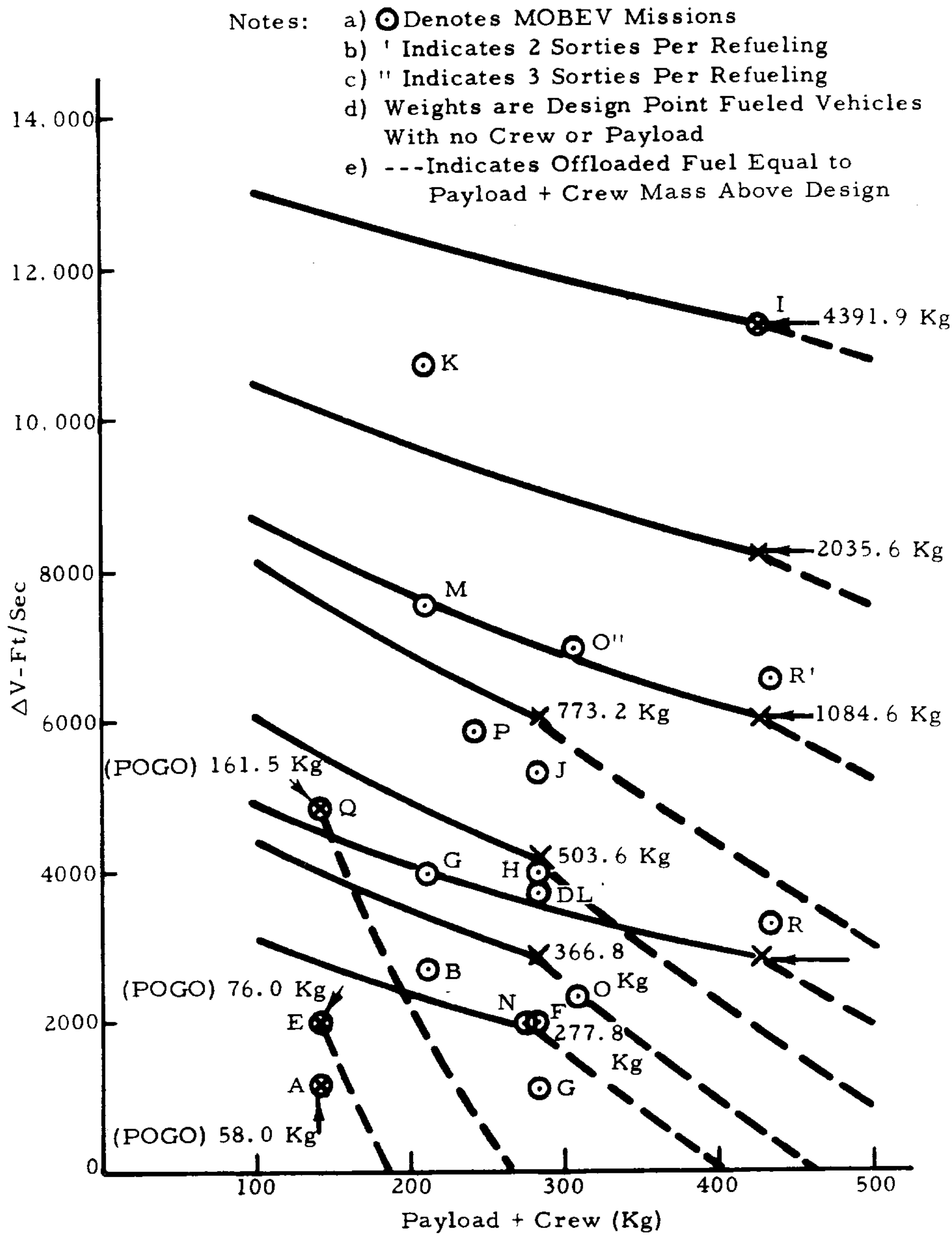

Figure 4-1 MOBEV LFX Mission Spectrum

TABLE 4-3

CHARACTERISTICS OF FLYING VEHICLE FOR ALSS RESCUE MISSION

Vehicle dry mass	183 kg
Propellants	261 kg
Gross mass	444 kg
Crew and payload	259 kg
Range	80.5 km
Trajectory	Ballistic or Constant altitude
Time requirements, worst case, from decision to abort through LM activation	102.7 min
Energy requirements	88.1 w hr

The MOLAB mission calls for an extended traverse constrained to an operating radius of 80 km or less from the landing point. The LFV is carried on the MOLAB. Its primary purpose is to return the MOLAB crew of two a maximum distance of 80 km to the LM.

Alternative uses, such as the exploration of otherwise inaccessible features, have also been proposed. With an assumed payload of 45 kg, the three typical excursions shown in Table 4-4 can be performed for a total ΔV of 884 m/sec from an available ΔV of 1650 m/sec. The flights involve differences in elevation as well as distance

4.3.2 Apollo Extension Systems (AES)

The AES study is discussed in Section 2.2.2.1 from the standpoint of LRV applications. Missions utilizing lunar flying vehicles will be treated here. The AES flyer is called the Manned Flying System (MFS). Table 4-5 summarizes the MFS mission requirements.

TABLE 4-4

TYPICAL EXPLORATION SORTIES FOR LUNAR FLYING VEHICLE

Sortie Description	Δx (m)	Δh (m)	ΔV (m/sec)
Station to Crater Rim	1620	305	240
Crater Rim to Crater Floor	3230	-610	305
Crater Floor to Station	4850	305	296
Total			884

TABLE 4-5

BASELINE MISSION OPERATION REQUIREMENTS FOR THE MFS

	Baseline Missions	
REQUIREMENTS	MFS	LSSM/MFS
Maximum Crew Size	1	2
No. of Sorties	2	2
Sortie Duration-hr	6	6
No. of Flights	4	4
Total Range-km	23	24
Range per Flight-km	6, 6, 5.5, 5.5	7, 7, 5, 5
Flight Preparation Time-min	22	22
Unloading/Activation Time-hr	3	3
Maximum Scientific Payload-kg	135	135
Maximum Sample Return-kg	35	35
Refueling Capability	Not required	Not required

The range capabilities of the MFS are considerably less than for roving vehicles of comparable delivered mass. The amount of time spent at distant scientific stations is limited, and the scientific payload which can be carried is also reduced. Table 4-6 shows the MFS scientific payload for the baseline mission.

4.3.2.1 Missions Utilizing Single MFS

Because of the limited range of the MFS, the number of sorties is fixed at two. Other scientific activities outside the shelter will be conducted on foot; however, landing sites can be selected to provide a variety of features within walking distance. With an extra PLSS, the astronaut will be able to remain on station for five hours on each MFS sortie. The 10-ft drill and the seismic experiments have been eliminated. The 100-ft drill may still be used at the LM-Shelter. Deleted equipment is replaced by instrumentation for use at the base, including equipment for more advanced astronomical experiments.

4.3.2.2 Missions Utilizing MFS and LSSM

The mobility and safety aspects of this combined mission are discussed in Section 2.2.2.1. The utilization of the MFS is in principle the same as for the case in which no LSSM is available. The addition of the LSSM extends the area which can be reached by other means than the MFS, but at the expense of scientific instrumentation. The recommendation in the Scientific Mission Support Study is for the elimination of the 100-ft drill and the Emplaced Scientific Station.

TABLE 4-6

NOMINAL MFS SORTIE PAYLOAD

	Mass (kg)
Scientific Instrumentation	
Tissue equivalent ion chambers	0.9
Acoustic ejecta detector	0.5
Theodolite/ranging laser	22.8
Surveying markers	0.8
Sketchboard and maps	2.3
Surveying staff	13.2
Staff tracking systems	7.0
Sample containers	1.0
Hand tools	15.0
Gravimeter	6.8
Magnetometer	3.9
Penetrometer	2.8
Mass spectrometer	7.0
Surface electrical	13.1
Radiometry	4.0
Subtotal	101.1
Integration and Interface Equipment	
Communications	13.8
Data-handling and signal conditioning	9.0
Power	5.5
Equipment stowage	3.0
Subtotal	31.3
Total Payload	132.4

SECTION 5

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